# Central Venous Catheterization and Central Venous Pressure Monitoring

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Central venous access remains a cornerstone of resuscitation and critical care in both the emergency department (ED) and intensive care unit. Advanced hemodynamic monitoring, rapid infusion of fluid, placement of transvenous pacemakers, and administration of selected medications all require reliable central venous access. Central venous catheterization has also gained acceptance in the resuscitation and treatment of critically ill children (see Chapter 19). Traditionally, the subclavian vein (SV), internal jugular (IJ) vein, and femoral vein have provided reliable and easily obtainable vascular access through the use of identifiable anatomic landmarks. Over the past decade, the increased availability of, training in, and provider competence in bedside ultrasonography have had a significant impact on the standard approach to both peripheral and central venous catheterization. Ultrasound-guided central venous catheterization has improved success rates, reduced complication rates, decreased the time required to perform the procedure, and resulted in overall cost savings.

The various techniques described in this chapter each have inherent advantages and disadvantages, but all have a place in the practice of emergency medicine. Frequently, a clinician's previous experience with a particular technique determines the preferred approach, but clinicians responsible for acute resuscitation of the ill and injured should master several of these techniques.

## HISTORICAL PERSPECTIVE

In 1667, the first known central venous catheter (CVC) was placed into a human IJ vein by Lower for a blood transfusion into the carotid artery of a sheep.[1] Modern central venous catheterization heralds back to at least 1928 when Werner Forssmann, a 25-year-old German surgeon, performed a venous cutdown on his own left antecubital vein, inserted a ureteral catheter to a distance of 65 cm, and then climbed several flights of stairs to the radiology suite to confirm that it terminated in the right atrium. Although the hospital fired Dr. Forssmann for not obtaining permission, he went on to win the 1956 Nobel Prize for his pioneering efforts.[1,2]

Duffy reported a large series of femoral, jugular, and antecubital vein catheterizations in 1949.[3] Aubaniac developed subclavian venipuncture while working on French Army casualties between 1942 and 1952.[4] His infraclavicular SV approach was refined by Keeri-Szanto in 1956, and the supraclavicular approach to the vein was first described by Yoffa in 1965.[5,6] Aside from Duffy's earlier work, Hermosura (1966) and English (1969) are generally credited with scientific development of the percutaneous IJ approach.[7]

The most important advancement in modern CVC came in 1953 when the Swedish radiologist Sven Seldinger had the idea of advancing large catheters over a flexible wire that was inserted through a percutaneous needle.[8,9] The role of central venous pressure (CVP) monitoring in the maintenance of optimal blood volume helped popularize central catheterization in the United States.[10] This was accelerated by the advent of the pulmonary artery catheter, which was developed by Jeremy Swan and William Ganz in 1968.[11] Swan, who was inspired by his observations of a sailing boat during a picnic with his children, developed a flow-directed balloon that allowed measurement of pulmonary artery pressure.[12]

## ANATOMY

### SV System

The SV begins as a continuation of the axillary vein at the outer edge of the first rib. It joins the IJ vein to become the innominate (sometimes referred to as the brachiocephalic) vein 3 to 4 cm proximally. The SV has a diameter of 10 to 20 mm, is approximately 3 to 4 cm long, and is valveless. After crossing over the first rib, the vein lies posterior to the medial third of the clavicle. It is only in this area that there is an intimate association between the clavicle and the SV. The costoclavicular ligament lies anterior and inferior to the SV, and the fascia contiguous to this ligament invests the vessel. Posterior to the vein and separating it from the subclavian artery is the anterior scalene muscle, which has a thickness of 10 to 15 mm. The phrenic nerve passes over the anterior surface of the scalene muscle laterally and runs immediately behind the junction of the SV and the IJ vein. The larger thoracic duct (on the left) and the smaller lymphatic duct (on the right) pass over the anterior scalene muscle and enter the SV near its junction with the IJ vein. Superior and posterior to the subclavian artery lies the brachial plexus. The dome of the left lung may extend above the first rib, but the right lung rarely extends this high (Fig. 22-1).

### IJ Vein

The IJ vein begins just medial to the mastoid process in the jugular foramen at the base of the skull and is formed by the inferior petrosal sinus and the sigmoid sinus. It runs inferiorly and passes under the sternal end of the clavicle to join the SV and form the innominate or brachiocephalic vein. At the level of the thyroid cartilage, the IJ vein, the internal carotid artery, and the vagus nerve course together in the carotid sheath just deep to the sternocleidomastoid (SCM) muscle. Within the carotid sheath, the IJ vein typically occupies the anterior lateral position and the carotid artery lies medial and slightly posterior to the vein. This relationship is relatively constant, but studies have found that the carotid artery may overlap the IJ. Note that normally the IJ vein migrates medially as it nears the clavicle, where it may lie directly over the carotid artery. When using the most common (central) approach, the IJ tends to be more lateral than expected.[13,14] Furthermore, in 5.5% of those studied, the IJ vein may even be medial to the carotid artery.[14-17] The relationship between the IJ vein and the carotid artery also depends on head position. Excessive head rotation can cause the carotid artery to rotate over the IJ vein.[18,19]

Anatomic landmarks for locating the vein include the sternal notch, the medial third of the clavicle, and the SCM.

# Central Venous Catheterization

## Indications

Central venous pressure monitoring
High-volume/flow resuscitation
Emergency venous access
Inability to obtain peripheral venous access
Repetitive blood sampling
Administering hyperalimentation, caustic
  agents, or other concentrated fluids
Insertion of transvenous cardiac pacemakers
Hemodialysis or plasmapheresis
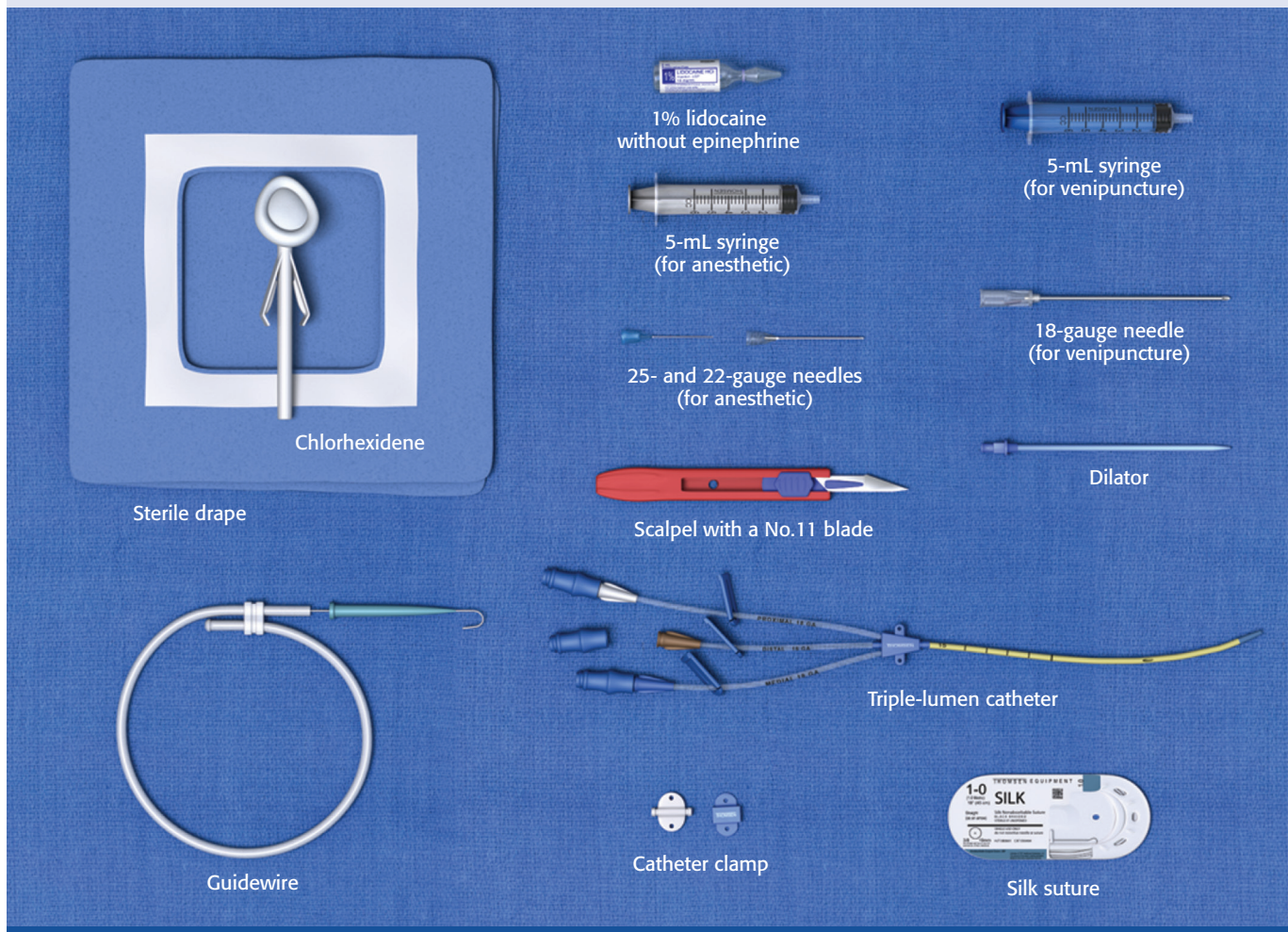Insertion of pulmonary artery catheters

## Contraindications

Infection over the placement site
Distortion of landmarks by trauma or congenital anomalies
Coagulopathies, including anticoagulation and thrombolytic therapy
Pathologic conditions, including superior vena cava syndrome
Current venous thrombosis in the target vessel
Prior vessel injury or procedures
Morbid obesity
Uncooperative patients

## Complications

Arterial puncture and hematoma
Pneumothorax (subclavian and internal jugular approach)
Hemothorax (subclavian and internal jugular approach)
Vessel injury
Air embolism
Cardiac dysrhythmia
Nerve injury
Infection
Thrombosis
Catheter misplacement

## Equipment (contents of a typical central venous catheterization kit)



1% lidocaine without epinephrine

5-mL syringe (for venipuncture)

5-mL syringe (for anesthetic)

18-gauge needle (for venipuncture)

25- and 22-gauge needles (for anesthetic)

Chlorhexidene

Dilator

Sterile drape

Scalpel with a No.11 blade

Guidewire

Triple-lumen catheter

Catheter clamp

Silk suture

**Review Box 22-1** Central venous catheterization: indications, contraindications, complications, and equipment.
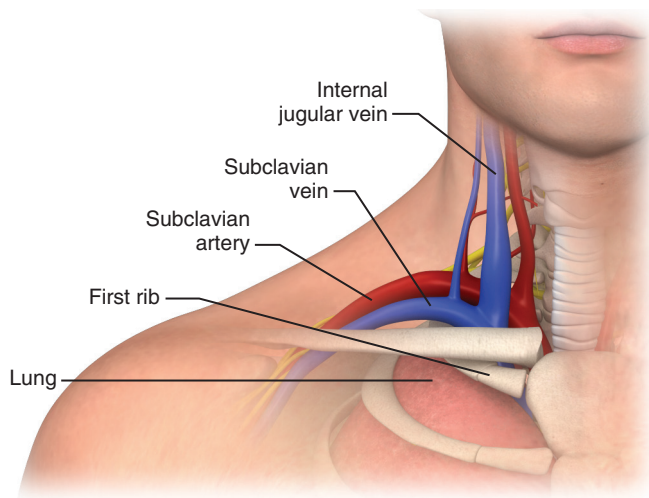
**Figure 22-1** Subclavian vein anatomy. The subclavian vein runs parallel to the clavicle and anterior to the subclavian artery. The cupula of the lung lies just caudad to these structures. If the introducer needle is kept almost parallel to the clavicle, the artery and lung should not be encountered.



**Figure 22-2** Internal jugular anatomy. The internal jugular vein runs parallel and lateral to the carotid artery but lies almost directly above the carotid artery at the level of the clavicle.

The two heads of the SCM and the clavicle form a triangle that is key to understanding the underlying vascular anatomy. The IJ vein can be located at the apex of the triangle as it courses along the medial head of the SCM and occupies a position in the middle of the triangle at the level of the clavicle before it joins the SV and forms the innominate vein. At the level of the thyroid cartilage, the IJ vein can be found just deep to the SCM.

Generally, the right IJ is bigger than the left IJ because of its connection to the SV and the right atrium. The IJ vein can be pulsatile, but in contrast to the aorta, these pulsations are not palpable. When visualized, however, the presence of venous pulsations can give an indication of patency of the IJ vein to the right atrium. The IJ vein also changes size with respiration. Because of the negative intrathoracic pressure at end-inspiration, blood in the IJ vein is actually drawn into the right atrium and the diameter of the IJ vein shrinks. In contrast, at end-expiration the increased intrathoracic pressure will limit return of blood to the right atrium and the diameter of the IJ vein will increase. Another unique characteristic of the IJ vein is its distensibility. The IJ vein will enlarge when pressure in the vein is increased, such as when flow of blood back to the right atrium is obstructed, as with thrombosis. This distensibility can be advantageous for the placement of central venous access. Use of a head-down (Trendelenburg) position or a Valsalva maneuver will increase the diameter of the IJ vein and thereby increase the likelihood of successful puncture (Fig. 22-2).

### Femoral Vein

The femoral anatomy is less complex than that of the neck and shoulder and contains fewer vital structures. The femoral vein is most easily cannulated percutaneously in patients with a palpable femoral pulse. The femoral vein begins at the adductor canal (also known as Hunter's canal) and ends at the inferior margin of the inguinal ligament, where it becomes the external iliac vein. It is contained within the femoral triangle (inguinal ligament, medial border of the adductor longus, and lateral border of the sartorius muscle). Medially,
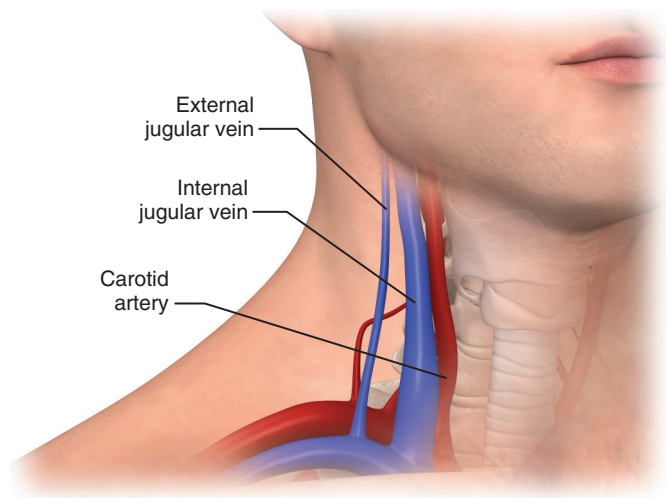
the femoral vein abuts a robust system of lymphatics. Laterally, the vein is intimately associated with the femoral artery. The femoral nerve courses down into the leg just lateral to the femoral artery. These relationships from lateral to medial can be remembered with the mnemonic NAVEL (nerve, artery, vein, empty space, lymphatics). Note that as the femoral artery and vein course down the leg within the femoral sheath, their side-by-side relationship frequently rotates such that the femoral artery may lie on top of the vein. Therefore, to avoid arterial puncture, keep cannulation attempts just under the inguinal ligament. When cannulating this vessel distal to the inguinal ligament, ultrasound guidance can be helpful to avoid arterial puncture (Fig. 22-3).

### INDICATIONS

Central venous access has several clinical indications (see Review Box 22-1). If necessary, any central venous approach could be used for each of these situations. However, certain approaches offer advantages over others in specific clinical settings. The clinical indications are discussed in detail in the following sections.[20-22]

### CVP Monitoring and Oximetry

For a period, pulmonary artery catheterization somewhat supplanted CVP monitoring; however, there is little evidence that this practice has any benefit with regard to patient mortality or quality of life. In the specific setting of resuscitation of patients in septic shock, CVP monitoring has reemerged as an important component of "early goal-directed therapy."[23,24] Continuous or episodic measurements of central venous $O_2$ saturation play a prominent role in current protocols for the aggressive treatment of septic shock.[23,24]

Central venous catheterization is widely used as a vehicle for rapid volume resuscitation. Notwithstanding, short large-caliber peripheral catheters can be as effective as central access because of the properties of Poiseuille's law, which states that the rate of flow is proportional to the radius of the catheter and inversely proportional to its length.[3] To illustrate, the
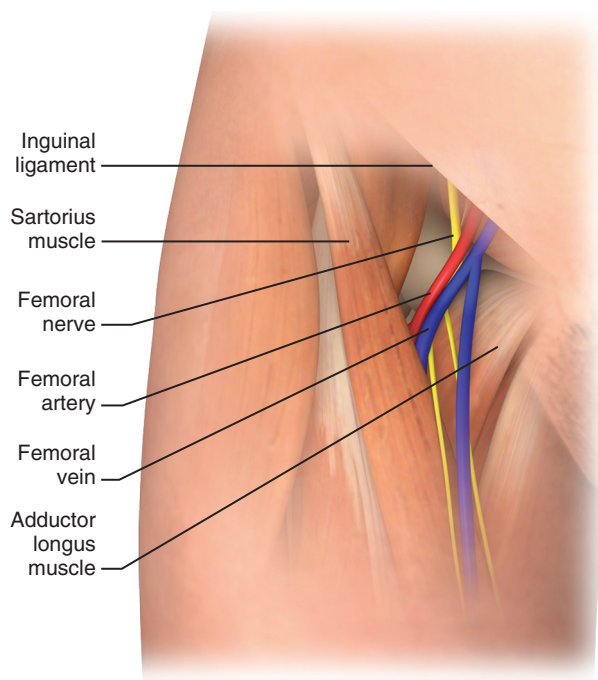
**Figure 22-3** Femoral vein anatomy. The femoral vital structures are located in the femoral triangle: inguinal ligament superiorly, sartorius muscle laterally, and adductor longus muscle medially. The triangle can be remembered by the mnemonic "SAIL" (*s*artorius, *a*dductor longus, and *i*nguinal *l*igament). Note the femoral structures from lateral to medial: *n*erve, *a*rtery, *v*ein, *e*mpty canal, and *l*ymphatics (mnemonic—NAVEL). The femoral vein lies medial to the femoral artery. *Important anatomic note:* At sites more distal from the inguinal ligament, the vein lies directly above the artery.

gravity flow rate of saline through a peripheral 5-cm, 14-gauge catheter is roughly twice that through a 20-cm, 16-gauge CVC. Consequently, placement of large-bore peripheral catheters is generally the fastest method of volume loading.

## Delivery of High-Flow Fluid Boluses and Blood Products

The advent of thermoregulating high-volume rapid infusers affords the advantage of using central venous catheterization in the setting of severe hemorrhagic shock or hypothermia. The available systems can infuse blood warmed to 37°C through an 8.5-Fr introducer sheath 25% more rapidly than through a 14-gauge peripheral intravenous (IV) line and up to 50% faster than through an 18-gauge peripheral IV line.[25] The Level 1 Rapid Infuser and the Belmont FMS 2000 are examples of modern systems with infusion rates as high as 1500 mL/min.[25] Massive air embolism was a concern with early rapid infusers, but safety precautions have now been engineered to prevent this. Still, if the catheter is misplaced, fluid or blood can be rapidly infused into the thorax, mediastinum, or peritoneum with serious consequences.

## Emergency Venous Access and Inability to Achieve Peripheral Access

The predictable anatomic locations of the subclavian and femoral veins and the speed with which they can be cannulated have prompted their use in cardiac arrest and other emergency situations. The need for a central line during cardiopulmonary resuscitation (CPR) is controversial.[26-28] When achieved easily, central venous cannulation, especially via the IJ or SV route, is preferred over peripheral venous access because it provides a rapid and reliable route for the administration of drugs to the central circulation of patients in cardiac arrest. With resuscitation for aortic catastrophes or thoracoabdominal trauma, two CVCs, "one above and one below" the diaphragm, are often used.

Patients with a history of IV drug use, major burns, chronic disease, dehydration, or morbid obesity and those who require long-term access may have inadequate peripheral IV sites. Central venous cannulation may be indicated as a means of venous access in these patients even under non-emergency conditions.[29] More recently with the use of ultrasound, deep brachial, axillary, and basilic vein cannulation may be attempted before central venous catheterization. This approach avoids the complications that can be associated with central venous access.

## Routine Serial Blood Drawing

The potential complications of CVCs make them inappropriate solely for routine blood sampling. However, lines already in place may be used for this purpose if they are properly cleared of IV fluid. A 20-cm, 16-gauge catheter contains 0.3 mL of fluid, so at least this much must be withdrawn to avoid dilution of blood samples. Moreover, to avoid aspiration of crystalloid-diluted blood from the peripheral vein, it is advised that the IV line be turned off for at least 2 to 3 minutes before using the catheter for a blood draw. Because of the increased risk for infectious complications, air embolism, and venous backbleeding, the IV tubing should not be repeatedly disconnected from the catheter hub. Interposition of a three-way stopcock in the IV tubing simplifies access and is an acceptable method for sampling blood in the intensive care setting, regardless of the IV site. The oxygen level in blood from the SV can be determined for guidance in early goal-directed therapy for sepsis if one chooses not to place a continuous oximetric monitor.

Additionally, serial lactate levels may help guide early goal-directed resuscitation. With an imbalance in oxygen supply ($Do_2$) and consumption ($Vo_2$), tissue hypoperfusion and hypoxia lead to anaerobic metabolism. The final product of this process is lactate. Arterial lactate levels would best represent overall perfusion since such samples contain blood coming from the pulmonary veins, superior vena cava (SVC), and inferior vena cava (IVC). Peripheral lactate preferentially reflects perfusion and metabolism in the compartment from which the blood was drawn, but not overall perfusion. Arterial and central venous lactate correlate closely more than 96% of the time, whereas peripheral venous lactate and arterial lactate correlate only 87% of the time.[30]

## Infusion of Hyperalimentation and Other Concentrated Solutions

Central venous hyperalimentation is safe and reliable. Use of the infraclavicular subclavian technique frees the patient's extremities and neck; this procedure is therefore well suited for long-term applications. Hyperosmolar or irritating solutions with the potential to cause thrombophlebitis if given through small peripheral vessels are frequently infused

**TABLE 22-1**    Advantages and Disadvantages of Central Venous Access Techniques

| TECHNIQUE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| IJ | Good external landmarks<br>Improved success with ultrasound<br>Less risk for pneumothorax than with SV access<br>Can recognize and control bleeding<br>Malposition of the catheter is rare<br>Almost a straight course to the superior vena cava on the right side<br>Carotid artery easily identified | More difficult and inconvenient to secure<br>Possibly higher infectious risk than with SV access<br>Possibly higher risk for thrombosis than with SV access |
| Femoral | Good external landmarks<br>Useful alternative with coagulopathy | Difficult to secure in ambulatory patients<br>Not reliable for CVP measurement<br>Highest risk for infection<br>Higher risk for thrombus |
| SV, infraclavicular | Good external landmarks | Unable to compress bleeding vessels<br>"Blind" procedure<br>Should not be attempted in children younger than 2 yr |
| SV, supraclavicular | Good external landmarks<br>Practical method of inserting a central line in cardiorespiratory arrest | "Blind" procedure<br>Unable to compress bleeding vessels |

*CVP*, central venous pressure; *IJ*, internal jugular; *SV*, subclavian vein.

through central veins. Examples are potassium chloride (>40 mmol/L), hyperosmolar saline, 10% calcium chloride (but not calcium gluconate, which can safely be given peripherally), 10% dextrose infusions, chemotherapeutic agents, and acidifying solutions such as ammonium chloride. Vasoactive substances (e.g., dopamine, norepinephrine) are best administered through a CVC because they may cause soft tissue necrosis if extravasation occurs in peripheral sites.

Central catheters, though safer than peripheral IV lines, are not immune to extravasation; indeed, fatal cases have been reported if the catheter becomes wedged up against the vessel wall, valves, or endocardium.[31] Strategies to avoid this complication include delivering vesicant drugs only through the distal ports or reconfirming that the proximal port is safely in the vein by aspirating blood through it.[31]

### Other Indications

Other indications for central venous access include insertion of a pulmonary artery catheter or transvenous pacemaker, cardiac catheterization, pulmonary angiography, and hemodialysis. A pulmonary artery catheter can be valuable for determining fluid and hemodynamic status in the critically ill. Its widespread use in the 1980s and 1990s drew heavy criticism because data showing a benefit in patient-oriented outcomes were lacking. Pulmonary artery catheters have subsequently lost popularity and should be used only when the diagnostic benefits outweigh the potential risks.[32,33] Catheters such as the Uldall and Quinton devices can be inserted within minutes, thereby permitting emergency or short-term hemodialysis. However, these catheters are very large and relatively stiff and have been known to perforate the vena cava or atrial walls, with fatal outcomes.[34,35] Extra caution should be applied during their insertion, possibly under ultrasound or fluoroscopic guidance.

### CONTRAINDICATIONS

General contraindications to the various techniques of central venous access are presented in Review Box 22-1. Table 22-1 lists the general advantages and disadvantages with each approach. Most contraindications listed are relative and should be viewed in the context of the patient's overall condition, urgency of need, and availability of alternative options for vascular access. Perhaps the only true absolute contraindication is insertion of catheters impregnated with antibiotics (most commonly tetracycline, rifampin, or chlorhexidine) if the patient has a serious allergy to the drug.[36,37] Local cellulitis and distorted local anatomy or landmarks are relative contraindications to any access route. Each technique is contraindicated in patients with distorted local anatomy or landmarks preventing safe insertion. Insertion of catheters through freshly burned regions, though somewhat challenging, is not associated with a higher incidence of infection until approximately 3 days after the burn, when bacterial colonization accelerates.[38,39] One of the more commonly encountered impediments to CVC placement is morbid obesity.[40] Surface landmarks in the neck are often obscured, and an abdominal pannus can block the femoral access site and consequently require deeper insertions and steeper angles. An ultrasound-guided IJ approach is safer under these circumstances.[40] Insertion of another catheter on the same side as a preexisting one risks the complication of entrapment.[41] Combativeness is an important factor in the decision to place a CVC because the risk for mechanical complications greatly increases in uncooperative patients. Sometimes it is best to sedate and intubate critically ill patients before attempting central venous catheterization. Other relative contraindications include conditions predisposing to sclerosis or thrombosis of the central veins, such as vasculitis, previous long-term cannulation, or illicit IV drug use via any of the deep venous systems.

Coagulopathy is a frequent concern surrounding insertion of a CVC, with the overall risk for clinically significant hemorrhage in these patients approximating 2%.[42] A transfusion of fresh frozen plasma is commonly used to correct any existing coagulopathy. However, a recent review concluded that if good technique is used, correction of coagulopathy is not generally required before or during the procedure.[43] Mumtaz and coworkers found that even in thrombocytopenic patients (platelet count <50 × 10⁹/L), bleeding complications occurred about 3% of the time and were limited to bleeding at the insertion site[44]; these complications were managed with additional sutures. Although the occasional patient may require a blood transfusion or replacement of clotting factors if a hemorrhagic complication arises, prophylactic correction of an abnormal international normalized ratio or platelet count before the procedure is not routinely necessary.[43-45] Risk can be further reduced in coagulopathic patients with the use of ultrasound-guided placement techniques.[14,46-49]

## Subclavian Approach

SV access is contraindicated in patients who have previously undergone surgery or sustained trauma involving the clavicle, the first rib, or the subclavian vessels; those with previous radiation therapy involving the clavicular area; those with significant chest wall deformities; and those with marked cachexia or obesity. Patients with unilateral deformities not associated with pneumothorax (e.g., fractured clavicle) should be catheterized on the opposite side. Subclavian venipuncture is not contraindicated in patients with penetrating thoracic wounds unless the injuries are known or suspected to involve the subclavian vessels or SVC. Generally, cannulate the vein on the same side as the chest wound to avoid the possibility of bilateral pneumothoraces. When (preexisting) SV injury is suspected, cannulate on the opposite side. Exercise greater caution when placing a CVC in the SV in coagulopathic patients because this vessel is not compressible. Formerly, subclavian venipuncture was not recommended for use in small children, but in experienced hands it has been demonstrated to be safe.[50-52]

## IJ Approach

Cervical trauma with swelling or anatomic distortion at the intended site of IJ venipuncture is the most important contraindication to the IJ approach. Likewise, the presence of a cervical collar is problematic. Although bleeding disorders are relative contraindications to central venous cannulation, the ultrasound-guided IJ approach is preferred over the SV route because the IJ site is compressible. However, prolonged compression of the artery to control bleeding could impair the cerebral circulation if collateral blood flow is compromised. In a study by Oguzkurt and colleagues, only minor bleeding complications occurred in less than 2% of patients after ultrasound-guided IJ catheterization.[47] In the setting of severe bleeding diatheses, the ultrasound-guided femoral approach is an acceptable alternative. Ultrasound-guided IJ placement is preferred in patients with abnormal anatomy from previous IJ trauma, small IJ vessels, and morbid obesity. Historically, carotid artery disease (obstruction or atherosclerotic plaque) is a relative contraindication to IJ cannulation because inadvertent puncture or manipulation of the artery could dislodge

a plaque. If a preceding SV catheterization has been unsuccessful, the ipsilateral IJ route is generally preferred for a subsequent attempt. In this manner, bilateral iatrogenic complications can be avoided.

## Femoral Approach

Contraindications to femoral cannulation include known or suspected intraabdominal hemorrhage or injury to the pelvis, groin, iliac vessels, or IVC. Additionally, avoid the femoral approach when known or suspected deep venous thrombosis is present. Palpation for femoral pulsations during CPR is difficult, and the pulsations are often venous rather than arterial.[28,53] Ultrasound-guided catheterization of the femoral vein during CPR is more successful and less likely than the standard landmark-oriented approach to incur inadvertent arterial puncture.[28]

## PROCEDURE

The most commonly used method for central venous cannulation is the Seldinger (guidewire) technique, in which a thin-walled needle is used to introduce a guidewire into the vessel lumen. Seldinger originally described this technique in 1953 as a method of placing a catheter for percutaneous arteriography.[17] The Seldinger technique is illustrated in Figure 22-9. To obtain vascular access, insert a small needle into the intended vessel. Once the introducer needle is positioned within the lumen of the vessel, thread a wire through the needle and then remove the needle. The wire, now within the vessel, serves as a guide over which the catheter is inserted. Although the Seldinger technique involves several steps, it can be performed quickly once mastered. More importantly, this technique broadens the application of central venous cannulation by permitting the insertion of standard infusion catheters, multilumen catheters, large-bore rapid infusion systems, introducer devices, hemodialysis devices, and even peripheral cardiopulmonary bypass cannulas. Given this flexibility, the use of Seldinger-type systems is advantageous despite their greater cost.

Ultrasound guidance has revolutionized the cannulation of central veins. As with all anatomic structures in the human body, veins are highly variable in their location. Not surprisingly, research has demonstrated that the ability to see the internal structure's location and proximity to other structures greatly increases the safety and success rate while decreasing the time required to perform the procedure.[46-49,54-56] These advantages have been recognized by national organizations. In a report from the Agency for Healthcare Research and Quality (AHRQ), use of ultrasound guidance was listed as one of the top 10 ways to reduce morbidity and mortality.[57] Many hospitals now require the use of ultrasound guidance for the placement of all CVCs.

The basic materials required for central venous cannulation are shown in Review Box 22-1 and are discussed in further detail below. The catheter may be a component in a guidewire system or may be of the over-the-needle variety (the other widely used method for catheter placement). Several types of CVC Seldinger-type prepackaged kits are commercially available, and the variations in each kit are discussed in the next section.

## EQUIPMENT

Preparation and organization of equipment ahead of time are imperative for a successful procedure. Most catheters now come from the manufacturer in convenient sterile kits. We strongly recommend stocking all additional equipment such as sterile gowns, gloves, and drapes in a dedicated "central line cart." This is a fundamental part of the "bundling" practice that has been shown to reduce the search for supplies, improve compliance with full-barrier technique, and subsequently decrease catheter-related infections.[58-63] Sterile barrier precautions with cap, face mask, sterile gown, and gloves should be used at all times during insertion of CVCs.[61,64,65]

### Ultrasound

Historically, many clinicians preferred to first locate the position of a central vein with a small exploratory or "finder" needle rather than directly cannulating the vein with a larger needle to accommodate a guidewire or catheter. This practice is less practical for the SV approach and has largely been replaced with the use of bedside ultrasound. Ultrasound-guided CVC placement allows the provider to survey the anatomy before the procedure, guide insertion of the needle into the correct vessel, and confirm placement of the catheter in the vessel.[14,47-49] See the Ultrasound Box.

### Needle

Virtually any needle or catheter can be used to introduce a guidewire into a vessel, but there are advantages to using needles specifically designed for passage of a guidewire. These needles must be large enough to accommodate the desired wire yet be as small as possible to minimize bleeding complications. The introducer needles provided with CVCs or introducer devices are usually thin walled to maximize lumen size relative to the overall needle diameter. If a needle that is not thin walled is used, choose a size that is 1 gauge smaller (larger bore) than that listed in Table 22-2. If unsure, simply test the equipment first to ensure compatibility.

Standard needles may have a uniformly straight-bore lumen throughout their length. A wire passing into a straight needle may encounter an obstacle at the proximal end. The proximal end of a Seldinger needle incorporates a funnel-shaped taper that guides the wire directly into the needle (Fig. 22-4). It is advisable to use a non–Luer-Lok or slip-tip type of syringe because the added twisting that is required to remove a Luer-Lok syringe from the introducer needle may dislodge a tenuously placed needle. Safety syringe systems exist that permit passage of the wire without removal of the aspirating syringe by using a central tunnel in the barrel. This device incorporates a hollow syringe through which the guidewire can pass directly into the introducing needle without detachment. It also reduces the risk for air embolism, which can occur when the needle is open to air. It is not uncommon for the wire to become snagged at the junction of the safety syringe and the needle hub. In this case, simply remove the syringe and insert the wire directly.

### Guidewire

Two basic types of guidewires are used: straight and J shaped. Straight wires are for use in vessels with a linear configuration,

**TABLE 22-2**   Needle Sizes for Venous and Arterial Catheters*

| STANDARD FULL-LENGTH COIL GUIDEWIRE CATHETER SIZE (Fr) | NEEDLE GAUGE[†] |
|---|---|
| 3 | 21 |
| 4-4.5 | 20 |
| 5-6.0 | 20-19 |
| 6-8.5 | 19-18 |

*Any size of catheter from 3.0 to 8.5 Fr may be introduced with a 22-gauge needle if a solid wire (e.g., Cor-Flex, Cook Critical Care) is used.
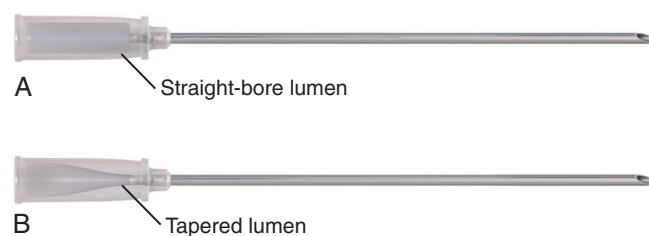[†]All needle gauges are for thin-walled needles only, the type supplied in central line kits.



**Figure 22-4** Introducing needles. **A,** Ordinary needle with a straight-bore lumen. **B,** Seldinger needle with a tapered lumen, which allows easy entry of the guidewire.
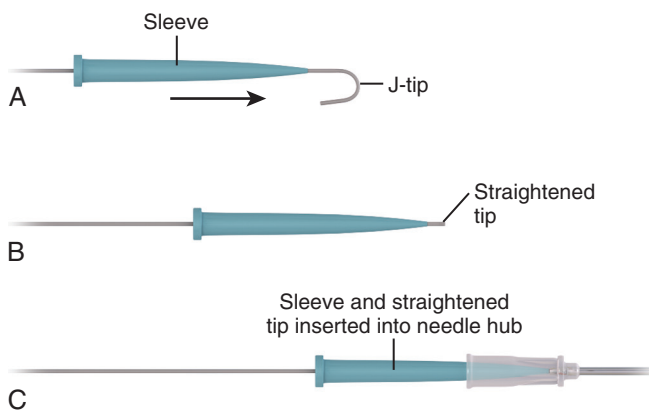


**Figure 22-5** J-wire. **A,** Plastic sleeve in the retracted position demonstrating the J-tip. **B,** Plastic sleeve advanced to straighten the curve for easy introduction into the needle hub. **C,** Plastic sleeve inserted into needle hub. In an emergency, take care to not misplace or throw the sleeve away. Without it, placing the J-wire into the hub of the needle is very difficult. Some wires may have a "soft-tipped" straight end on the opposite end of the wire. These wires are engineered to be flexible (to avoid vessel injury) and may be used if there is difficulty passing the J end.

whereas J-wires are for use in tortuous vessels. Both wires have essentially the same internal design (Fig. 22-5). The flexibility of the wire is the result of a stainless steel coil or helix that forms the bulk of the guidewire. Within the central lumen of the helix is a straight central core wire, called a mandrel, that adds rigidity to the steel coil. The mandrel is usually fixed at one end of the helix and terminates 0.5 and 3.0 cm from the other end to create a flexible or floppy tip. Wires are also available with two flexible ends, one straight

and the other J shaped. The flexible end of the guidewire allows the wire to flex on contact with the wall of a vessel. If the contact is tangential, as with an infraclavicular approach to the SV, a straight wire is generally preferred. If the angle is more acute, as with an external jugular approach to the SV, or if the vessel is particularly tortuous or valves must be traversed, a J-shaped wire may be used. The more rounded leading edge of the J-wire provides a broader surface to manipulate within the vessel and decreases the risk for perforation. This is especially advantageous when attempting to thread a wire through a vessel with valves. Many guidewires also contain a straight safety wire that runs parallel to the mandrel to keep the wire from kinking or shearing.

The standard size for guidewires is 0.025 to 0.035 inch (0.064 to 0.089 cm) in diameter, which permits introduction through an 18-gauge thin-walled needle. A modification of this standard wire uses a bare mandrel with the flexible coil soldered to its end. This construction provides a wire with a diameter of just 0.018 inch (0.047 cm) but with the same rigidity as the larger wires. The manufacturer states that such a wire can be introduced through a 22-gauge thin-walled needle yet still guide an 8.5-Fr catheter (Micropuncture Introducer Sets and Trays with Cor-Flex Wire Guides, Cook Critical Care, Inc., Bloomington, IN).

It is important to emphasize that guidewires are delicate and may bend, kink, or unwind. A force of 4 to 6 lb may cause a wire to rupture. Wires should thread easily and smoothly and never be forced; the worst complications of CVC placement are associated with the application of excessive force across parts of the apparatus that are not threading smoothly.[66] If a wire is not passing easily, withdraw the wire and the introducer needle as a single unit. Embolization of portions of the guidewire is possible, and sharp defects in the wire may perforate vessel walls (Fig. 22-6). If one encounters a good flash of blood but cannot readily manipulate the wire, this may indicate that the outer wire coils are entrapped against the proximal sharp edge of the needle bevel. The J can be straightened remotely by applying gentle force on the wire in each direction, which may allow retrieval of the wire.[55] Wires should be inspected for small defects such as kinks, sharp ends, or spurs before use and especially after a failed attempt. Wires may be threaded into the introducer needle hub more easily by using the plastic sleeve attached to the wire as shown in Figure 22-5C.

## Catheters

A number of different catheter and introducer devices have been developed, and the method of passage into the vessel varies accordingly. The functions of catheters have become more sophisticated as well, most notably for continuous monitoring of central venous oxygen saturation and cardiac output. Generally, one can place single-, double-, and triple-lumen catheters by sliding the catheter directly over a guidewire into the intended vessel (Fig. 22-7A). Catheter insertion lengths are listed in Table 22-3. Larger catheters or devices without lumens can be introduced with a sheath-introducer system. Over-the-needle catheters can be introduced once intravascular placement is attained.

The Desilets-Hoffman–type sheath introducer became available in 1965 to aid in arteriography procedures that require many catheter changes. This device is commonly but incorrectly termed a "Cordis," which is a proprietary trade
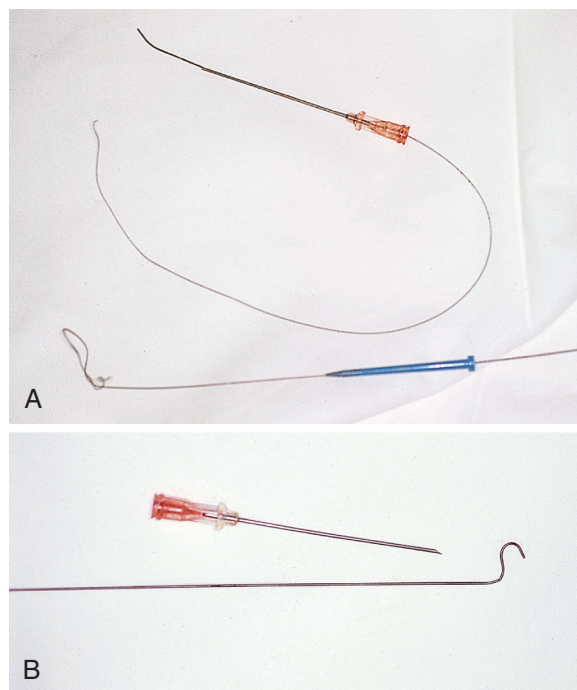


**Figure 22-6**  **A** and **B,** Although newer guidewires are more resistant to shearing, if a guidewire will not advance, *withdraw both the needle and the wire in one motion*. These pictures demonstrate a permanently deformed guidewire that could not be advanced. Withdrawing the wire with the indwelling introducer needle in place within a vessel may shear off a portion of the wire and result in systemic embolization.

name. The sheath-introducer unit includes two parts, an inner dilator and an outer sheath as shown in Figure 22-7B. The dilator is rigid with a narrow lumen to accommodate the guidewire. It is longer and thinner than its sheath and has a tapered end that dilates the subcutaneous tissue and vessel defect created by the needle. The sheath (or introducer catheter when used as a cannula for inserting Swan-Ganz catheters, transvenous pacemakers, or other devices) has a blunt end and is simply a large-diameter catheter.

Many modifications of the sheath exist, such as side arms and diaphragms to aid in the placement of devices without lumens. Care must be taken when using side-arm sets for rapid administration of fluid because some catheters are 8.5 Fr in diameter but have only a 5-Fr side arm. Some sets have a "single-lumen infusion catheter," which performs the same function but is more easily secured to the sheath introducer. Selection of the appropriate diameter of introducer catheter should correspond to the indication for placement of a CVC. Generally, an 8.5-Fr catheter is used to facilitate placement of a Swan-Ganz catheter and a 6.0-Fr catheter is used to facilitate transvenous placement of a pacemaker. If the introducer catheter is larger than required to support the intraluminal device, a leak may develop at the diaphragm insertion point.

Special catheters have been developed to prevent bacterial contamination and line sepsis.[37,67,68] These catheters are impregnated with either antiseptics (silver sulfadiazine and chlorhexidine) or antibiotics (minocycline, rifampin, or cefazolin) to reduce bacterial colonization and microbial growth. Also, heparin-coated catheters are available that prevent fibronectin binding, thereby inhibiting the formation
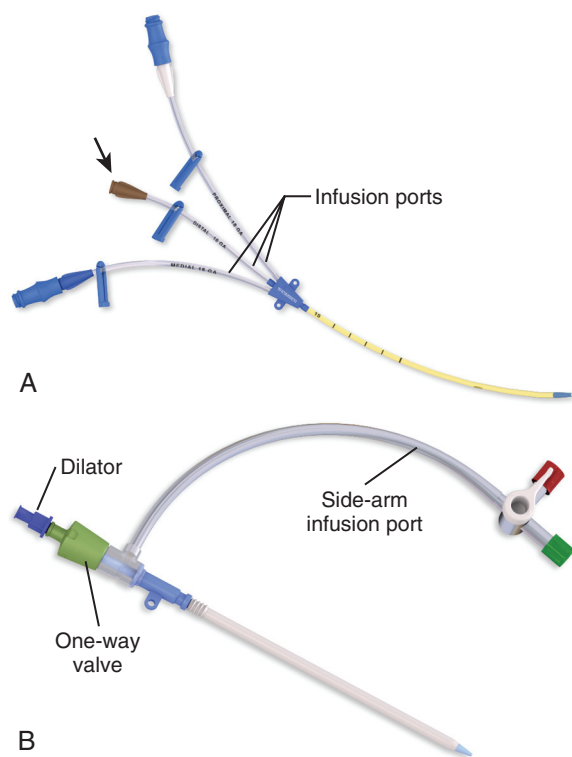
**Figure 22-7 A,** Triple-lumen catheter. The catheter ports are used for infusion of fluids, administration of medications, and monitoring of central venous pressure and are typically labeled as proximal, medial, and distal. The distal or brown port, typically 16 gauge, facilitates passage of the guidewire. Note that the end cap of the distal port (arrow) must be removed before insertion to allow passage of the guidewire. **B,** Sheath introducer. This large-bore device (8.5 Fr) is used as an introduction catheter for devices such as Swan-Ganz catheters and transvenous pacemakers. Note that the dilator must be placed through the catheter *before* the device is inserted into the patient.

**TABLE 22-3**   Formulas for Catheter Insertion Length Based on Patient Height and Approach

| SITE | FORMULA | IN SVC (%) | IN RA (%) |
|------|---------|-----------|-----------|
| RSC | (Ht/10) − 2 cm | 96 | 4 |
| LSC | (Ht/10) + 2 cm | 97 | 2 |
| RIJ | Ht/10 | 90 | 10 |
| LIJ | (Ht/10) + 4 cm | 94 | 5 |

From Czepizak C, O'Callaghan JM, Venus B. Evaluation of formulas for optimal positioning of central venous catheters. *Chest*. 1995;107:1662. Reproduced by permission.
*Ht*, patient height (in cm); *LIJ*, left internal jugular; *LSC*, left subclavian; *RA*, right atrium; *RIJ*, right internal jugular; *RSC*, right subclavian; *SVC*, superior vena cava.

of bacterial biofilm on the catheter's surface. These catheters can decrease catheter-associated infection (CAI) significantly and are cost-effective when the prevalence of CAI is greater than 2%.[42] They should be avoided in patients with a history of heparin-induced thrombocytopenia.[69] Minocycline- and rifampin-impregnated catheters are currently considered to be the most effective.[37,67] Other interventions that decrease

central line infections include the use of full sterile barrier precautions,[61,65] skin preparation with chlorhexidine solution,[61-63,70] and placement by experienced physicians.[65,71-73]

Many different catheters are currently manufactured. Although this leads to great flexibility in choice and cost, it often results in confusion when a clinician is handed an unfamiliar catheter during an emergency. It is best to use one brand routinely and to ensure that all medical personnel are thoroughly familiar with its use.[74]

## TECHNIQUE

### Preprocedure Preparation

When possible, discuss the procedure with the patient and obtain written informed consent. Place the patient and yourself in an appropriate position for the specific vessel being accessed. If available, perform an ultrasound survey to identify the patient's anatomy, ensure vessel patency, and confirm the puncture site (Fig. 22-8). Ultrasound-guided CVC placement has been shown to decrease procedure times, as well as complication rates.[46-49] Additionally, compliance with a central line bundling policy has been shown to significantly decrease central line–associated bloodstream infections.[60-63] Prepare and drape the puncture site while maintaining sterile technique, and observe universal precautions throughout the procedure (Fig. 22-9, *steps 1 and 2*). A gown, surgical cap, mask, eye protection, and sterile gloves should be worn throughout the procedure when possible. When performing ultrasound-guided placement of a CVC, ensure that a sterile transducer sheath and sterile transducer gel are used during the procedure (see Fig. 22-9, *step 3*). Using an assistant will prove valuable in patient preparation, maintenance of sterility, and handling of the equipment.

### Guidewire Placement with the Seldinger Technique

When performing ultrasound-guided placement of a CVC, begin with an ultrasound survey of the target vein, surrounding structures, and venipuncture location, as shown in Figure 22-8. Veins can easily be distinguished from the nearby artery by applying external pressure with the transducer. Veins collapse completely with pressure, whereas arteries may deform but do not usually collapse. Occasionally, the vein does not collapse with pressure. If this occurs, a thrombus may be present in the vein or the structure has been misidentified. If a suspected vein does not collapse with pressure, it is not an appropriate vessel for cannulation. If available, Doppler functions may also be helpful in the differentiation of veins and arteries. Select a venipuncture location where branching of the vein will allow the shortest path of the needle, will not obstruct passage of the catheter, and will not allow inadvertent puncture of other vital anatomic structures. (See Chapter 66 for additional information and descriptions of the ultrasound technique.)

Prepare the catheter for insertion by flushing each lumen with sterile normal saline. Anesthetize the insertion site with lidocaine or bupivacaine (see Fig. 22-9, *step 5*). Attach a small syringe to an introducing needle that is large enough to accommodate the guidewire. Insert the needle and syringe together. Slowly advance the needle into the vein and apply steady negative pressure on the syringe (see Fig. 22-9, *step*
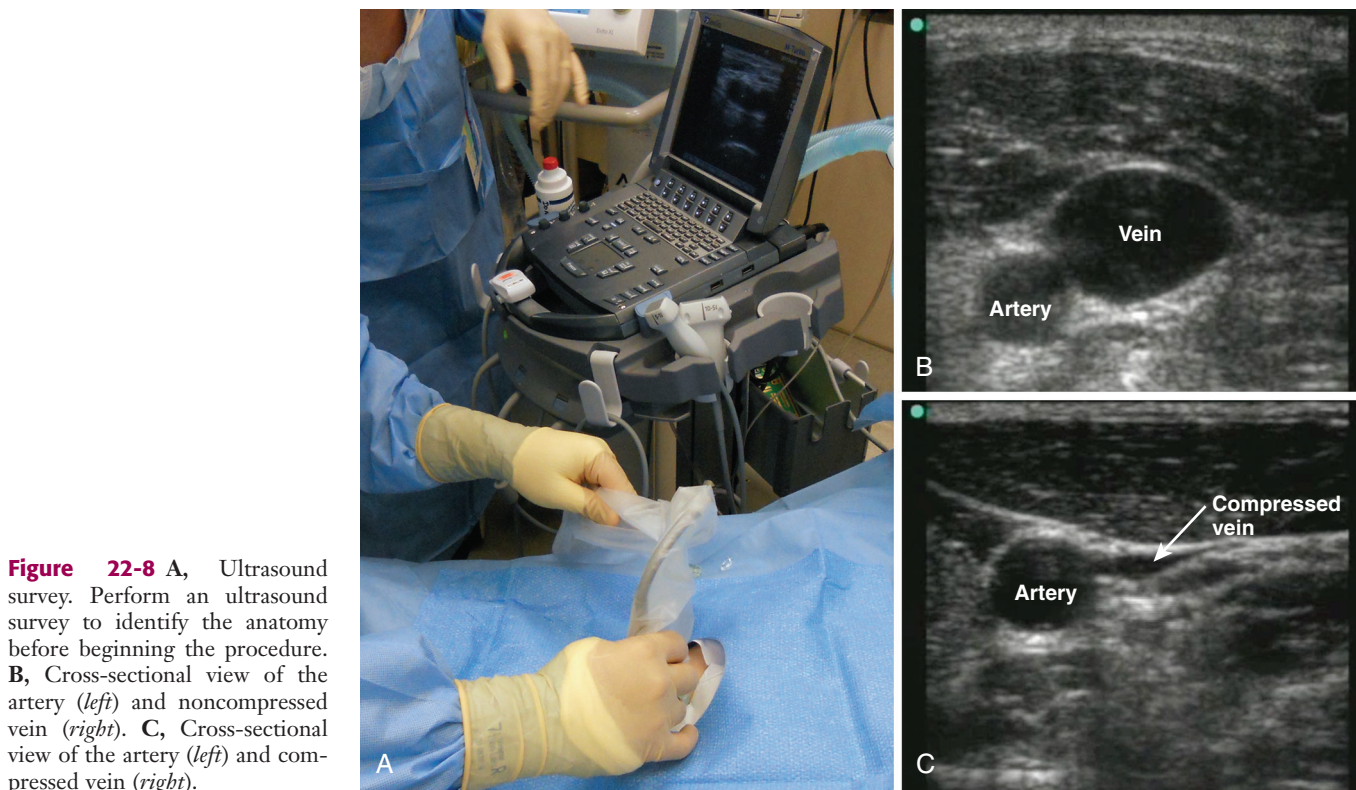
**Figure 22-8 A,** Ultrasound survey. Perform an ultrasound survey to identify the anatomy before beginning the procedure. **B,** Cross-sectional view of the artery (*left*) and noncompressed vein (*right*). **C,** Cross-sectional view of the artery (*left*) and compressed vein (*right*).

*6*). When performing ultrasound-guided CVC placement, follow the needle trajectory in the soft tissue and observe penetration of the vessel. If the tip of the needle is not visualized at all times with ultrasound, the needle may be passed into structures other than the vein. The key concept in using ultrasound guidance for venous access is to visualize the tip of the needle at all times during cannulation (Fig. 22-10). Once the tip of the needle enters the vessel lumen, blood will be aspirated freely. Stabilize the needle hub to prevent movement of the needle and displacement of the tip from the vessel, and remove the syringe. The need to disconnect the syringe can be eliminated by use of the Arrow Safety Syringe. After removing the syringe, cap the needle hub with your thumb before passing the guidewire to minimize the potential for air embolism.

Confirm that the blood flow is nonpulsatile. Bright red pulsatile blood is very suggestive of arterial puncture. Be aware that in shock states or marked arterial desaturation, dark, nonpulsatile blood does not rule out arterial cannulation. If there are concerns about possible arterial puncture, either remove the introducer needle and draw a sample for blood gas analysis from the needle to compare with an arterial blood gas sample or insert an 18-gauge single-lumen catheter over the wire and into the vessel because this step does not require the use of a dilator. The catheter can then be connected to a pressure transducer to confirm the presence of venous waveforms and venous pressure.

Introduce the flexible end of the guidewire into the hub of the needle (see Fig. 22-9, *step* 7). It may be easier to introduce the J-wire by advancing the plastic sleeve contained in the kit onto the floppy end of the wire to straighten the J shape. This straightened end is then introduced into the needle hub. The guidewire should thread smoothly through the needle into the vessel without resistance. Do not force the wire if resistance is encountered, but remove it from the needle and reattach the syringe to aspirate blood and reconfirm intravascular needle placement. It is important for the wire to slip easily from the needle during removal. If resistance to removal of the wire is felt, the wire and needle should be removed as a single unit to prevent shearing of the wire and resultant wire embolism. It has been recommended by some that no wire should ever be withdrawn through the introducing needle.[75] Although there are no clinical data to support this recommendation and newer wires are stronger and more resistant to shearing, it represents the safest course of action. The recommendation to remove the needle and wire as a unit is sometimes disregarded because of reluctance to abandon a potentially successful venipuncture. The clinician performing the procedure must use both caution and good judgment to determine the best course of action but should not withdraw the guidewire against resistance. Manipulation of the wire within an introducer needle should be done only with standard coil guidewires. Solid wires (such as Cor-Flex Wire Guides from Cook Critical Care) have a small lip at the point at which the flexible coil is soldered to the wire. This lip can become caught on the edge of the tip of the needle and shear off the coil portion of the wire. Solid wires must thread freely on the first attempt or the entire wire and needle assembly must be removed. Keep backup wires on hand.

Occasionally, a wire must be teased into the vessel; rotating the wire or needle often helps in difficult placements. If the wire does not thread easily, pull back slightly on the needle itself just before advancing the wire. This helps if the opening of the needle is abutting the vessel's inner wall and blocking entry of the wire or if the vein is compressed by introduction of the needle. Changing wire tips from a straight wire to a J-wire or vice versa may also solve an advancement problem. If the inner lumen of a vessel is smaller than the

# CENTRAL VENOUS CATHETERIZATION (INTERNAL JUGULAR APPROACH)



Prepare the area with chlorhexidine solution. A gown, surgical cap, mask, eye protection, and sterile gloves should be worn throughout the procedure.



Apply a full-body, sterile drape. Meticulous attention must be paid to sterile technique to avoid iatrogenic infection.



Insert the ultrasound probe into a sterile sheath, and use sterile ultrasound gel during the procedure. Enlist the help of an assistant in patient preparation and maintenance of sterility.
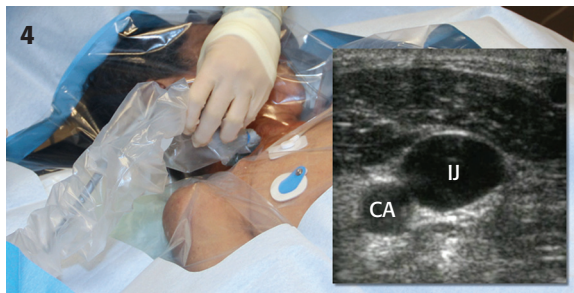


Identify the anatomic structures with ultrasound. The internal jugular vein (*IJ*) and carotid artery (*CA*) must be clearly distinguished from each other (see text for more details).



Anesthetize the tissues overlying the vein with local anesthetic. Here, the operator is using ultrasound guidance to ensure a proper entry site.



Insert the needle and syringe while slowly advancing and applying negative pressure to the plunger. Follow the needle trajectory with ultrasound until the vein is entered and blood enters the syringe (*arrow*).
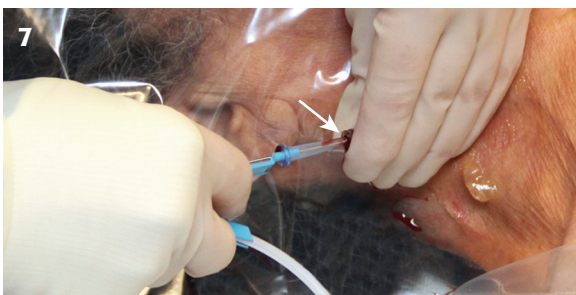


Remove the syringe and advance the guidewire through the needle. Use the straightener (*arrow*) to facilitate entry of the J-wire into the hub. NEVER FORCE THE WIRE!
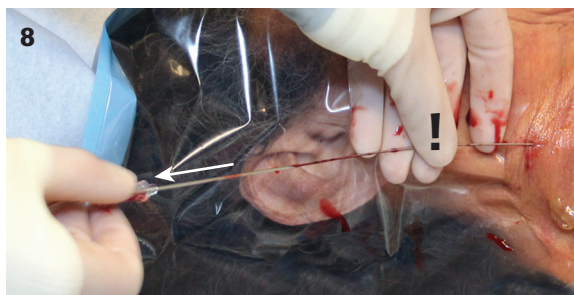


Once the wire has been inserted to the appropriate depth (see text for details), remove the needle (*arrow*). It is *essential* to *always* maintain a grip on the wire throughout the procedure (!).

**Figure 22-9** Ultrasound-guided internal jugular central venous catheterization.

*Continued*

# CENTRAL VENOUS CATHETERIZATION (INTERNAL JUGULAR APPROACH)



Make an incision at the site of the wire to facilitate dilator and catheter passage. Make the incision the width of the catheter and extend it completely through the dermis.



Thread the dilator over the guidewire. The wire must *always* be protruding from the end of the dilator and firmly in your grasp (!). Advance the dilator several cm into the vessel and then remove.
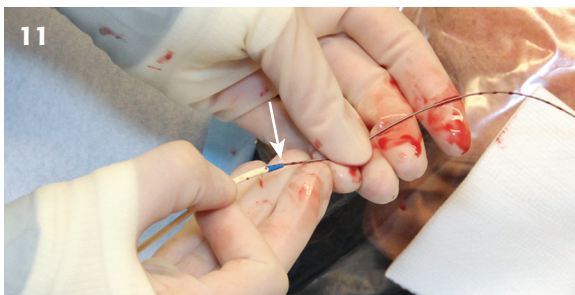


Advance the catheter over the wire. It can be difficult to align the two pieces; hold the very end of the catheter and the wire to make this step easier.
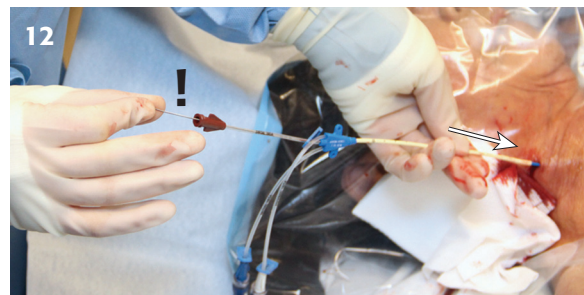


Advance the catheter into the vessel. The guidewire will emerge from the distal port. It is essential that the guidewire protrudes from the hub and is grasped before catheter advancement (!).
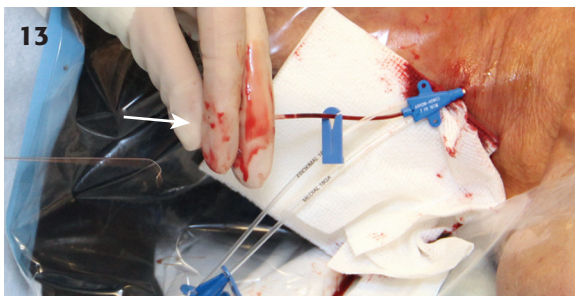


Remove the wire. Cover the open port with your thumb (*arrow*) until the end-cap is screwed on.



Flush all ports with saline.



Suture the catheter into place using non-absorbable silk sutures. Several knots should be made to secure the line. Avoid making knots that place excessive pressure on the skin.



Clean the area around the catheter insertion site with chlorhexidine. Place a simple dressing, avoiding excessive amounts of gauze and tape.
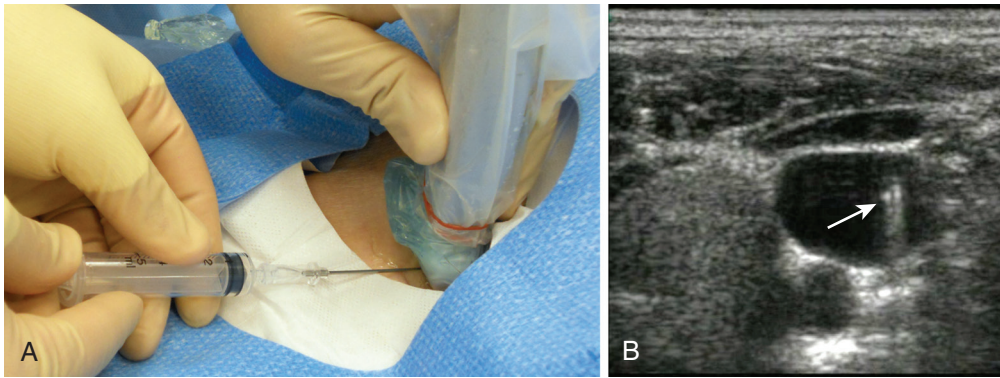
**Figure 22-9, cont'd**

**Figure 22-10 A,** Ultrasound-guided insertion of the introducer needle. **B,** Cross-sectional ultrasound image of the needle (*arrow*) within the vessel.

diameter of the J, the wire will be prevented from returning its natural shape and the spring in the coil will generate resistance. Any advantages of a J-wire will be negated if the wire fails to regain its intended shape. In this instance, a straight tip should be able to be introduced without a problem. Alternatively, if the angle of entry of the needle into the vessel is more acute than was suspected, a straight wire may not be able to bend appropriately as it encounters the vessel's far wall. A J-tipped wire may be used and threaded in such a manner that the wire resumes its J shape away from the far wall. All these maneuvers are performed with gentle free motions of the wire within the needle. If at any time the wire cannot be advanced freely, suspect improper placement and reevaluate the attempt.

If threading easily, advance the guidewire until at least one quarter of the wire is within the vessel. The further into the vessel the wire extends, the more stable its location when the catheter is introduced. However, advancing the guidewire too far may result in ventricular ectopy secondary to endocardial irritation, myocardial puncture leading to tamponade, or entanglement in a previously placed pacemaker, internal defibrillator, or IVC filter. In both the left and right IJ vein and infraclavicular SV approaches, fluoroscopic study during passage of the guidewire has determined the mean distance from skin to the SVC-atrial junction to be 18 cm.[75] This distance has been recommended as the greatest depth of guidewire insertion for these approaches. It should be noted that 18 cm is not necessarily the appropriate final depth for the catheter being placed (see discussion below).

Cardiac monitoring may be helpful during the insertion of central lines. Any increase in premature ventricular contractions or a new ventricular dysrhythmia should be interpreted as evidence that the guidewire is inserted too far and should be remedied by withdrawing the wire until the rhythm reverts to baseline. Usually, the procedure can be continued after a moment, with care taken to not readvance the wire. Persistent ventricular dysrhythmias require standard advanced cardiac life support treatment and consideration of a new vascular approach.

Occasionally, a wire threads easily past the tip of the needle and then suddenly will not advance farther. If the introducer needle demonstrated free return of blood at the time of wire entry and the initial advancement of the wire met no resistance, the two options are to halt the procedure or seek confirmation of wire position. The guidewire within the lumen of the vessel can be visualized and confirmed via cross-sectional and longitudinal views on ultrasound. Alternatively, the needle may be removed, the wire fixed in place with a
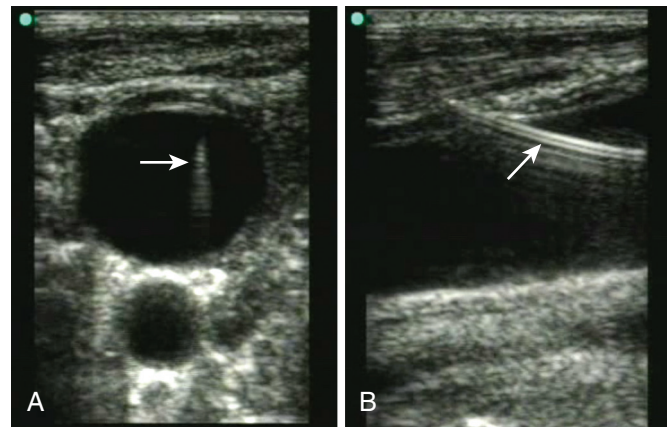


**Figure 22-11** Cross-sectional (**A**) and longitudinal (**B**) ultrasound images demonstrating a guidewire (*arrows*) in the lumen of the targeted vein.

sterile hemostat, and a radiograph taken to confirm the position of the wire.[75,76] A freely advancing wire may suddenly stop once it is well within a vessel if the vessel makes an unsuspected bend or is being compressed or deviated by another structure, such as a rib or muscle. This seems especially common with the infraclavicular approach to the SV and can sometimes be remedied by a more lateral approach.

## Sheath Unit and Catheter Placement

Once the wire is placed into the vessel, remove the needle in preparation for passage of the catheter (see Fig. 22-9, *step 8*). Proper positioning of the guidewire within the vessel lumen can be confirmed by cross-sectional and longitudinal ultrasound imaging (Fig. 22-11).[76] This can be done at any point while inserting the wire to ensure that the correct vessel has been cannulated and that puncture of the posterior wall has not occurred. This technique can be quite useful when resistance is encountered while feeding the guidewire. A small skin incision is required at the site of the wire to widen the opening (see Fig. 22-9, *step 9*). Make the incision approximately the width of the catheter to be introduced and extend it completely through the dermis.

When placing soft multiple-lumen catheters, the tissue must be dilated from the skin to the vessel before placement of the catheter. Thread the guidewire through the distal opening of the rigid dilator until it extends through the proximal end of the dilator (see Fig. 22-9, *step 10*). The wire must

always be visibly protruding from the end of the dilator or catheter during insertion to avoid inadvertent advancement of the wire into the circulation and potential loss of the wire. While maintaining control of the guidewire proximally, thread the dilator over the wire into the skin with a twisting motion. Advance the rigid dilator only a few centimeters into the vessel, and then remove it. Once the dilator is removed, thread the soft catheter into position over the wire. Placement of multiple-lumen catheters requires identification of the distal lumen and its corresponding hub. Find the distal lumen at the very tip of the catheter. The corresponding hub is usually labeled "distal" by the manufacturer. If there is any confusion, inject a small amount of sterile saline through each hub until it is observed exiting the distal lumen. Once the distal hub is identified, remove its cover cap to allow passage of the guidewire. Place the catheter by threading the guidewire into the distal lumen and advancing it until it protrudes from the identified hub (see Fig. 22-9, *step 11*). It is imperative that the guidewire protrude from the catheter hub and that it be firmly grasped as the wire and catheter are advanced. If the wire does not protrude from the proximal end of the catheter, withdraw the wire at the skin entry point until it protrudes enough to be grasped. While maintaining control of the guidewire proximally, advance the catheter into the vessel to the desired catheter insertion length (see Fig. 22-9, *step 12*). Ultrasonography can be used to verify proper catheter

placement. After insertion of the catheter the wire must be removed (see Fig. 22-9, *step 13*) and the catheter must be anchored to the skin with sutures. When removing the wire from a catheter it must slip out easily. If any resistance is met, remove both the wire and the catheter as a single unit and reattempt the procedure. A common cause of a "stuck wire" is a small piece of adipose tissue wedged between the wire and the lumen of the catheter. Avoid this problem by creating a deep enough skin nick and adequate dilation of the tract before inserting the catheter.

When placing a single-lumen, Desilets-Hoffman sheath-introducer system, the dilator and larger single-lumen catheter are inserted simultaneously as a dilator-sheath unit. The dilator-sheath unit must first be assembled by inserting the dilator through the catheter's diaphragm (Fig. 22-12, *step 2*). When assembled correctly, the dilator "snaps" into place within the lumen of the sheath and protrudes several centimeters from the distal end of the catheter.

After successful guidewire placement and after the skin incision is made, thread the dilator-sheath assembly over the wire (see Fig. 22-12, *step 3*). It is imperative that the guidewire protrude from the proximal end of the dilator-sheath assembly and that it be firmly grasped as the wire and unit is advanced. If the wire does not protrude from the proximal end of the assembly, withdraw the wire at the skin entry point until it protrudes enough to be grasped. While maintaining
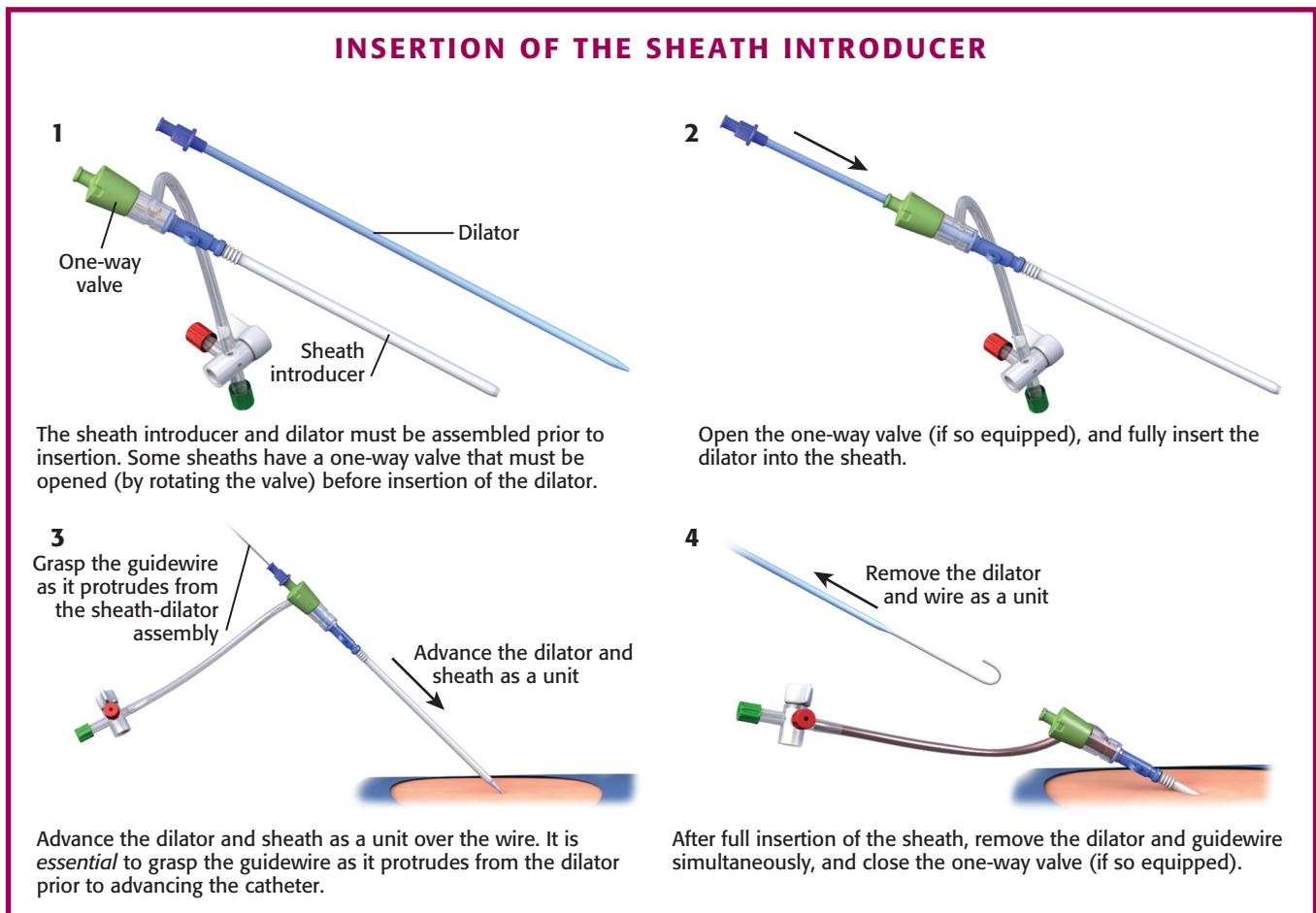


## INSERTION OF THE SHEATH INTRODUCER

**1**

One-way valve

Dilator

Sheath introducer

The sheath introducer and dilator must be assembled prior to insertion. Some sheaths have a one-way valve that must be opened (by rotating the valve) before insertion of the dilator.

**2**

Open the one-way valve (if so equipped), and fully insert the dilator into the sheath.

**3**

Grasp the guidewire as it protrudes from the sheath-dilator assembly

Advance the dilator and sheath as a unit

Advance the dilator and sheath as a unit over the wire. It is *essential* to grasp the guidewire as it protrudes from the dilator prior to advancing the catheter.

**4**

Remove the dilator and wire as a unit

After full insertion of the sheath, remove the dilator and guidewire simultaneously, and close the one-way valve (if so equipped).

**Figure 22-12** Insertion of the sheath introducer. Insertion of a sheath introducer varies slightly from that for a triple-lumen catheter—the dilator and the catheter are inserted simultaneously as depicted. The remainder of the steps are analogous to those in Figure 22-9. Once inserted, sheath introducers facilitate the placement of devices such as pulmonary artery catheters and transvenous pacemakers.

control of the guidewire proximally, advance the assembly through the skin with a twisting motion until it is within the vessel. Grasp the unit at the junction of the sheath and dilator. This prevents the thinner sheath from kinking or bending at the tip or from bunching up at the coupler end. Keep the assembly intact and advance it through the skin to the hub. Once the catheter is placed, remove the wire and dilator from the sheath simultaneously (see Fig. 22-12, *step 4*). When removing the wire and dilator, the dilator must "unsnap" from the sheath unit, and the wire must slip out easily. Once the single-lumen sheath-introducer catheter is placed correctly, it may be used to facilitate the placement of additional intraluminal devices such as a pulmonary artery catheter, transvenous cardiac pacemaker, or additional multiple-lumen catheter. At times, critically ill patients who require initial large-volume resuscitation will later require multiple medications and therapies that dictate the need for a multiple-lumen catheter. An alternative method of placing a multiple-lumen catheter is to thread the catheter through a standard Desilets-Hoffman sheath-introducer system.

It is important to consider the depth of insertion of the catheter (see Table 22-3). The proper depth of catheter insertion is site specific (see below). After successful CVC placement, the catheter should be anchored to the skin with sutures (see Fig. 22-9, *step 15*). Each port should be immediately capped and flushed with a saline solution (see Fig. 22-9, *step 14*). The catheter insertion site should be dressed appropriately and all sharp implements disposed of in appropriate receptacles (see Fig. 22-9, *step 16*).

## Replacement of Existing Catheters

In addition to placing new catheters, clinicians may use the guidewire technique to change existing catheters. Many patients with CVCs are seriously ill and will require subsequent monitoring of pulmonary artery wedge pressure, placement of a transvenous pacemaker, or insertion of a different catheter. The CVC that is initially inserted should have a lumen large enough to accept a guidewire and facilitate conversion to a different catheter. Clinicians may use the guidewire technique to change a single-lumen CVC to a triple-lumen catheter or a sheath-introducer set. Not all commercially available CVCs will accept a guidewire.

Replacement of an existing catheter begins with selecting a guidewire longer than either of the devices to be exchanged. Use meticulous aseptic technique.[70] Insert the guidewire into the existing CVC until a few centimeters of wire is protruding from the proximal end. With one hand holding the wire securely, remove the catheter and wire as a single unit until the tip of the catheter just clears the patient's skin. Grasp the wire at the point where it exits the skin and only then release the wire at the other end. Then slide the catheter off the wire and insert the new device in the normal fashion. Exercise caution with this technique because catheter embolization can occur, especially if a catheter is cut to allow use of a shorter guidewire for the exchange. In patients without evidence of line sepsis, exchanging the guidewire does not increase the incidence of CAI if performed properly.[70]

## Over-the-Needle Technique

An optional method for cannulation is to place an over-the-needle catheter percutaneously. Over-the-needle devices (such as the Angiocath) use a tapered plastic catheter that passes through the vessel wall into the lumen, with the tip of the needle being used as a guide. There are advantages with this system. The catheter does not pass through a sharp needle and there is less risk of shearing and resultant catheter embolization. Also, the hole made by the needle in the vessel wall is smaller than the catheter, thus producing a tighter seal. The IJ vein and SV via the supraclavicular approach are the most popular and appropriate approaches for this technique. These devices may be useful when rapid central venous access is required (e.g., in cardiac arrest). These catheters are not suitable for high-volume fluid resuscitation, and they are too small for passage of a pacemaker lead. Once the clinical situation stabilizes, exchange this device for a larger central catheter via the Seldinger technique.

Prepare the skin with chlorhexidine solution. Use a longer peripheral-type catheter (such as a 16-gauge, $5\frac{1}{4}$-inch angiocatheter) in an adult. Smaller-diameter devices, such as 20-gauge catheters, may be easier to pass but provide slower infusion rates. Attach the needle to a syringe, and slowly advance it into the vein with steady negative pressure applied to the syringe. This may be difficult because of the longer length of the needle relative to the catheter. When using bedside ultrasound, follow the trajectory of the needle into the soft tissues and visualize penetration of the vessel. With over-the-needle catheters, the needle extends a few millimeters past the tip of the catheter. Return of blood will be obtained when the tip of the needle is in the vein, although the catheter may actually be outside the lumen. If the needle is withdrawn before the catheter is advanced, the tip of the catheter will remain outside the vein. It is therefore important to advance the needle a few millimeters after the venous flash is seen and then hold it steadily while advancing the catheter into the vein. Secure the catheter and verify its placement as detailed later in this chapter.

## SITE SELECTION
### Subclavian Approaches

Subclavian venipuncture is the most frequently used means of achieving central venous access. The infraclavicular SV approach was the first popular means of central venous access and has been used widely for nearly half a century. It is useful in many clinical situations and relatively easy to learn. It is often the best approach in trauma because a cervical collar can interfere with the IJ technique. The supraclavicular SV approach may be preferable during CPR because it minimizes physical interference in chest compressions and airway management. In addition, the supraclavicular SV technique has been performed in the sitting position in patients with severe orthopnea. Finally, the left SV provides a more direct route to the SVC and is the preferred site for pacemaker placement and CVP monitoring.

### IJ Approach

The IJ vein provides an excellent site for placement of a CVC. However, there is a 5% to 10% risk for complications, with serious complications occurring in about 1% of patients.[46] Failure rates have been found to be 19.4% for landmark-placed IJ catheterization by a junior practitioner and 5% to 10% by a clinician with extensive experience.[77] Despite its

potential complications, the IJ vein is in many cases preferred over other options for central venous access. In contrast to the SV, arterial punctures are easier to control because direct pressure can be used, and the incidence of pneumothorax is lower. Hematoma formation is easier to diagnose because of the close proximity of the IJ vein to the skin. In addition, the right IJ vein provides a straight anatomic path to the SVC and right atrium. This is advantageous for passage of catheters or internal pacemaker wires to the heart. Disadvantages of IJ vein cannulation over other sites include a relatively high carotid artery puncture rate and poor landmarks in obese or edematous patients.[40,46]

The IJ technique is useful for routine central venous access and for emergency venous access during CPR because the site is removed from the area of chest compressions. The differences in morbidity between the SV and the IJ vein approach have probably been overstated.[20,73,78,79] Catheter malposition is more frequent in the SV, but the risk for infection is probably slightly higher with IJ sites.[20,22,42,65] The rate of arterial puncture is higher with IJ attempts, but the SV is not a compressible site.[20,42] Though counterintuitive, the evidence available does not support a significant difference in the rate of pneumothorax and hemothorax.[20,42] Although there may be a slight difference in complications between the two routes, in the absence of specific contraindications clinicians should use the technique with which they are most familiar. The rapid development of real-time ultrasound guidance may tip the scales toward the IJ as the preferred site.[14,47-49,80,81]

## Femoral Approach

Cannulation of the femoral vein for central venous access has become increasingly popular, especially for venous access, infusion ports, passage of transvenous pacemakers, and placement of pressure measurement catheters in critically ill patients.[81] The relatively simple and superficial anatomy surrounding the femoral vein affords a rapid approach to the central venous system and avoids many of the more significant complications associated with cannulation of the IJ vein and SV. These benefits are tempered somewhat by several long-term disadvantages, including higher infection rates and an increased risk for venous thrombosis. Other indications for ED femoral cannulation include emergency cardiopulmonary bypass for resuscitation purposes, charcoal hemoperfusion for severe drug overdoses, and dialysis access. The femoral area is less congested than the head and neck area with monitoring and airway equipment, and conscious patients who are still bedridden may turn their head and use their arms more freely without moving the central line. The femoral site is contraindicated in ambulatory patients who require central access.

## SPECIFIC VESSEL ACCESS TECHNIQUES

If SV or IJ vein approaches are planned, prepare the skin in the area, including puncture sites for both the infraclavicular and supraclavicular SV and IJ vein approaches. This permits the clinician to change the site after an unsuccessful attempt without repeating the preparation or having to obtain an interval chest radiograph. Prepare the area, including the ipsilateral anterior aspect of the neck, the supraclavicular fossa,

and the anterior chest wall 3 to 5 cm past the midline and the same distance above the nipple line. Prepare for femoral access by trimming groin hairs and applying chlorhexidine to cover an area the breadth of and extending 10 cm above and below the inguinal ligament.

Each approach to central venous cannulation is described separately below. As with any invasive procedure, briefly describe the procedure to awake patients, and restate each step as it is about to be performed. After descriptions of the common approaches to the central veins, puncture site care, verification of placement, and other adjuncts to the procedure are summarized.

## Infraclavicular Subclavian Approach

Descriptions of subclavian venipuncture often focus unduly on angles and landmarks. Indeed, recent studies have demonstrated that some traditional positioning maneuvers may actually hinder successful cannulation efforts.

### Positioning

Place the patient supine on the stretcher with the head in a neutral position and the arm adducted at the side. Some authors have advocated various shoulder-, back-, head-, and arm-positioning maneuvers, but they take extra time and the help of an assistant and are often not helpful.[82-92]

We believe that the best position for almost all infraclavicular SV attempts is the neutral shoulder position with the arm adducted.[82-93] Turning the head away may be helpful but is certainly not required if cervical injuries are suspected.[83,85,90] Interestingly, Jung and colleagues found that in children, tilting the head toward the catheterization site improved catheter malposition rates.[94] This technique has not been studied in adults.

In difficult cases, placing a small towel roll under the ipsilateral shoulder[90] or having an assistant place caudal traction of about 5 cm on the extremity may also be helpful.[93] Placing the patient in a moderate Trendelenburg position (10 to 20 degrees) decreases the risk for air embolism.[85,95] The claim that this position distends the vein is controversial, but it may do so to a small favorable degree.[83,85,87] If the Trendelenburg position is impractical, the SV approach is probably less affected than the IJ approach when resorting to a neutral or even an upright position.[83,85,87]

Placing a pillow under the back is commonly recommended to make the clavicle more prominent, but as the shoulder falls backward, the space between the clavicle and the first rib narrows, thus making the SV less accessible.[92] Significant compression of the subclavian vessels between these bony structures occurs as the shoulders retract, which can cause a "pinch off" of the catheter as it slides through the SV between the clavicle and the first rib.[92,96]

### Venipuncture Site

The right SV is usually selected first because of the lower pleural dome on the right and the need to avoid the left-sided thoracic duct. The more direct route between the left SV and the SVC is a theoretical advantage of left-sided subclavian venipuncture; however, there is no higher incidence of catheter malposition when the right infraclavicular SV approach is used. In conscious patients, anesthetize the point of needle entry with 1% lidocaine. If possible, infiltrate the periosteum of the clavicle to make the procedure less painful. Opinions

vary regarding the best point of needle entry, more so than for the IJ or femoral approaches. With nonobese patients, look for the "deltopectoral triangle," which is bounded by the clavicle superiorly, the pectoralis major medially, and the deltoid muscle laterally.[88,97] The junction of the middle and medial thirds of the clavicle lies just medial to this triangle. Further medially, the vein lies just posterior to the clavicle and above the first rib, which acts as a barrier to penetration of the pleura. This protective effect is theoretically diminished when a more lateral location is chosen. However, when approaching the vein more medially, some clinicians have difficulty puncturing the SV, dilating the tissues, and passing the J-wire. Other recommended sites of approach include lateral and inferior to the junction of the clavicle and the first rib, with the needle aimed at this junction, and entry at the site of a small tubercle in the medial aspect of the deltopectoral groove. We recommend puncturing the skin at the lateral portion of the deltopectoral triangle via a shallow angle of attack.[88]

### Needle Orientation

Orient the bevel of the needle inferomedially to direct the wire toward the innominate vein rather than toward the opposite vessel wall or up into the IJ vein. Align the bevel of the needle with the markings on the barrel of the syringe to permit awareness of bevel orientation after skin puncture.

Before inserting the needle, place your left index finger in the suprasternal notch and your thumb at the costoclavicular junction (Fig. 22-13). These landmarks serve as reference points for the direction that the needle should travel. Aim the needle immediately above and posterior to your index finger. Watch for vessel entry, signaled by flashback of dark venous blood, which usually occurs at a depth of 3 to 4 cm. If the tip of the needle is truly intraluminal, there will be free-flowing blood. Return of pulsatile flow signifies arterial puncture, and the needle should be withdrawn immediately. A single arterial puncture without laceration rarely causes serious harm. Using this technique eliminates the need to measure angles, to



**Figure 22-13** Infraclavicular subclavian approach. Place your index finger in the suprasternal notch and your thumb at the costoclavicular junction; these landmarks will serve as reference points for the direction that the needle should travel. Orient the bevel of the needle inferomedially, and aim the needle above and posterior to your index finger.

"walk" the clavicle, or to concentrate excessively on maintaining the needle parallel to the chest wall. Avoid using sweeping motions of the tip of the needle to prevent unseen injuries.

### Unsuccessful Attempts

Cannulation of the SV may not succeed on the first attempt. It is reasonable to try again, but after three or four unsuccessful attempts, it is wise to move to a different anatomic approach or to allow a colleague to attempt the procedure. Use a new setup each time that blood is obtained because clots and tissue will clog the needle and mislead the clinician even if the vein has been entered successfully on subsequent attempts. If several attempts are made, inform the admitting clinician or anesthesiologist so that proper precautions are taken to identify subsequent complications. It is advisable to obtain radiographs of the chest even after unsuccessful attempts. If the initial puncture site was placed properly, use the same needle hole for subsequent attempts if possible for aesthetic reasons. If the SV route is unsuccessful on one side, attempt IJ vein catheterization on the same side rather than SV cannulation on the opposite side to avoid bilateral complications.

## Supraclavicular Subclavian Approach

### Positioning

The goal of the supraclavicular SV technique is to puncture the SV in its superior aspect as it joins the IJ vein. Insert the needle above and behind the clavicle, lateral to the clavicular head of the SCM muscle. Advance it in an avascular plane while directing it away from the subclavian artery and the dome of the pleura (Fig. 22-14). The right side is preferred because of the lower pleural dome, its more direct route to the SVC, and location of the thoracic duct on the left side. The patient's head may be turned to the opposite side to help identify the landmarks.

### Needle Orientation

After the area of the supraclavicular fossa has been prepared and draped, identify a point 1 cm lateral to the clavicular head of the SCM and 1 cm posterior to the clavicle. Alternatively, use the junction of the middle and medial thirds of the clavicle as the landmark for needle entry. Anesthetize the area with 1% lidocaine. If a 3-cm-long needle is used for anesthesia, it may also be used to locate the vessel in a relatively atraumatic manner. The SV can almost always be located with this needle because of its superficial location and the absence of bony structures in the path of the needle. Advance a 14-gauge needle (or 18-gauge thin-walled needle) along the path of the scout needle. Apply gentle negative pressure with an attached syringe.

When seeking the SV, aim the needle so that it bisects the clavicosternomastoid angle and the tip points just caudal to the contralateral nipple. Orient the bevel medially to prevent the catheter from getting trapped against the inferior vessel wall. Point the tip of the needle 10 degrees above the horizontal. Successful vessel puncture generally occurs at a depth of 2 to 3 cm.

### Subclavian Ultrasound Technique

Typically, puncture of the SV occurs at the point where the vein is coursing deep to the clavicle. However, with ultrasound, visualization of the SV can be difficult at this location because of interference with the overlying bone. Fortunately,
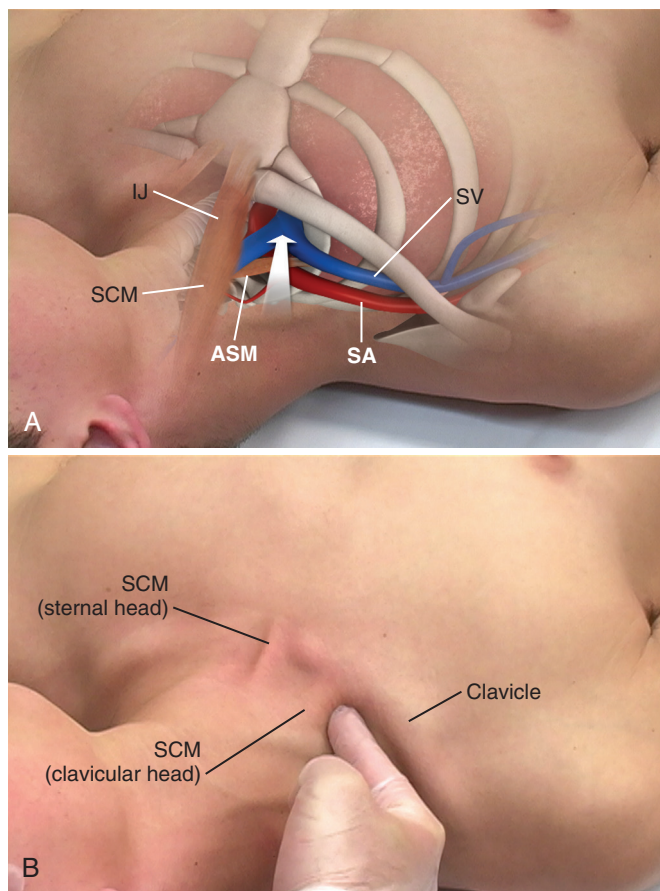
**Figure 22-14** Supraclavicular subclavian approach. **A,** Anatomy. As the subclavian vein passes over the first rib, it is separated from the subclavian artery by the anterior scalene muscle. The dome of the pleura is posterolateral to the confluence of the great veins. *Arrow,* needle target; *ASM,* anterior scalene muscle; *IJ,* internal jugular vein; *SA,* subclavian artery; *SCM,* sternocleidomastoid muscle, sternal head; *SV,* subclavian vein. **B,** Approach. Insert the needle 1 cm posterior to the clavicle and 1 cm lateral to the clavicular head of the SCM such that the angle made by the clavicle and lateral border of the muscle is bisected. The needle traverses an avascular plane and punctures the junction of the subclavian and IJ veins behind the sternoclavicular joint. The right side is preferred because of a direct route to the superior vena cava and absence of the thoracic duct. The needle is directed 45 degrees from the sagittal plane and 10 to 15 degrees upward from the horizontal plane and aimed toward the contralateral nipple. Note that the vein is just posterior to the clavicle at this juncture.

more distally the vein lies farther away from the clavicle and chest wall. Hence, access to the SV typically occurs lateral to the curve of the clavicle bone, in the proximal axillary vein. As the vein moves laterally, the mean depth from the skin increases from 1.9 to 3.1 cm while the distance from the rib cage to the vein increases from 1 to 2 cm. The arteriovenous distance also increases from 0.3 to 0.8 cm, and there is less overlap of the artery and vein.[98] Because the vein is not in close proximity to the clavicle, if a hematoma develops, manual pressure can be used to stop the bleeding. Furthermore, the axillary vein is farther from the chest wall and pleural surface, thus decreasing the possibility of pleural injury and subsequent pneumothorax. In clinical studies, ultrasound-guided axillary vein access had a first–needle pass

success rate of 76% with successful placement in 96% of cases. Despite the use of ultrasound, however, the catheter malposition rate was unchanged at approximately 15%.[99]

## IJ Approach

### *Positioning*

Position is critical for maximizing the success of blind (land-mark technique) cannulation of the IJ vein. Place the patient in a supine position with the head down and turned about 15 to 30 degrees away from the IJ vein to be cannulated. Rotate the head slightly away from the site of insertion. Rotating the head more than 40 degrees has been shown to increase the risk for overlapping the carotid artery over the IJ vein.[19] Occasionally, placing a towel roll under the scapula helps extend the neck and accentuate the landmarks. Stand at the head of the bed with all equipment within easy reach. This may involve moving the bed to the center of the room to allow a table or work surface to be placed at the head of the bed.

Ask the patient to perform a Valsalva maneuver just before inserting the needle to increase the diameter of the IJ vein. Alternatively, the patient can be asked to hum. Trendelenburg positioning, the Valsalva maneuver, and humming all increase the area of the vessel by about 30% to 40%.[100] If the patient is unable to cooperate, coordinate the insertion with respiration because the IJ vein is at its largest diameter just before inspiration. In intubated patients, this relationship is reversed because mechanical ventilation increases intrathoracic pressure at end-inspiration. External abdominal compression also helps distend the IJ vein.
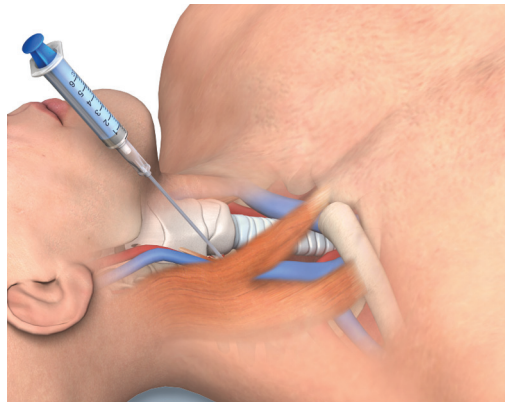
### *Venipuncture Site*

The right IJ vein provides a more direct route to the right atrium for transvenous pacing. The left IJ vein is often more tortuous and catheters must negotiate two 90-degree turns at the junction of the left IJ vein with the SV and at the junction of the SV with the SVC. However, if the right IJ vein is obstructed or scarred by previous access, the left IJ vein may be accessed with the same technique. Of note, the right IJ vein has been observed to be twice the size of the left IJ vein in 34% of normal adults.[101]

Aspirate before injecting anesthetic so that it is not injected into the carotid artery or IJ vein. Once infiltration is completed, use the needle to locate the IJ vein by aspirating blood into the syringe. Note the depth and angle of needle entry and use this as a mental guide to finding the IJ vein with the introducer needle. Typically, an 18-gauge 2.5-cm introducer needle attached to a syringe is used initially to puncture the IJ vein. However, needle selection may vary depending on the central line kit used. The operator may choose from three approaches: central, posterior and anterior (Fig. 22-15).

### Central Route

This approach is favored by some who believe that the incidence of cannulation of the carotid artery is decreased and the cupula of the lung is avoided.[101] First, palpate and identify the triangle formed by the clavicle and the sternal and clavicular heads of the SCM. Use a marking pen or a local anesthetic skin wheal to mark the lateral border of the carotid pulse, and perform all subsequent needle punctures lateral to this point.

When using the scout needle technique, attach a 22-gauge, 3-cm needle to a 5- to 10-mL syringe. Insert the needle near the apex of the triangle and direct it caudally at an angle
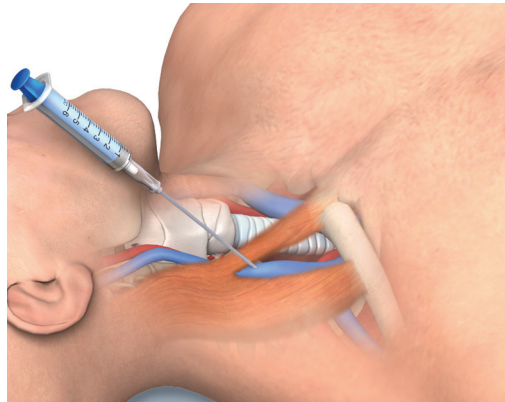
**ANTERIOR APPROACH**

Insert needle along the medial edge of the sternocleidomastoid, 2–3 fingerbreadths above the clavicle.

Entry angle = 30° to 45°.

Aim towards the ipsilateral nipple.

Note: Palpate the carotid artery during venipuncture. The artery may be slightly retracted medially.

**CENTRAL APPROACH**

Insert needle at the apex of the triangle formed by the heads of the sternocleidomastoid muscle and the clavicle.

Entry angle = 30°.

Aim towards the ipsilateral nipple.

Note: Estimate the course of the IJ vein by placing three fingers lightly over the carotid artery as it runs parallel to the vein. The vein lies just lateral to the artery, albeit often minimally so.
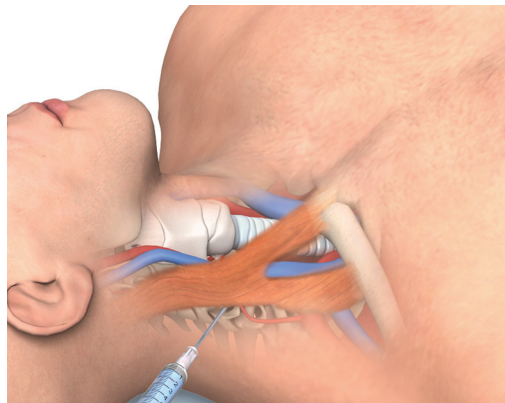
**POSTERIOR APPROACH**

Insert needle at the posterior (lateral) edge of the sternocleidomastoid, midway between the mastoid process and the clavicle.

Entry angle = 45°.

Aim towards the suprasternal notch.

Note: Avoid the external jugular vein, which crosses the posterior SCM border. During needle advancement, apply pressure to the SCM to lift the body of the muscle. The vein is usually reached at a depth of 7 cm.

**Figure 22-15** Approaches to the internal jugular (IJ) vein. *SCM*, sternocleidomastoid.

of 30 to 40 degrees to the skin. Direct the needle initially parallel and slightly lateral to the course of the carotid artery. Estimate the course of the IJ vein by placing three fingers lightly over the course of the carotid artery as it runs parallel to the vein. The vein consistently lies just lateral to the carotid artery, albeit often minimally so. Prolonged deep palpation of the carotid artery may decrease the size of the vein, so use the three-finger technique lightly to identify the course of the artery.

## Posterior and Anterior Routes

In the posterior approach, make the puncture at the posterior (lateral) edge of the SCM approximately midway between its origin at the mastoid process and its insertion at the clavicle. The external jugular vein courses in this area and can be used as a landmark, with the puncture occurring where the external jugular vein crosses the posterolateral border of the SCM. Be careful to not strike the external jugular vein. Advance the needle toward the suprasternal notch, just under the belly of the SCM, at an angle of approximately 45 degrees to the transverse plane. During advancement of the needle, apply pressure to the SCM in an effort to lift the body of the muscle. The vein is usually reached at a depth of 7 cm in an average-sized adult. Because the posterior approach occurs higher in the neck, there is less risk for hemothorax, pneumothorax, or carotid puncture.[102] The benefits of the posterior approach are more dramatic in obese patients, with carotid puncture occurring in 3% of patients versus up to 17% with the anterior approach.[103]

In the anterior approach, needle puncture occurs along the anterior or medial edge of the SCM about two to three fingerbreadths above the clavicle. Insert the needle at an angle of 30 to 45 degrees toward the ipsilateral nipple, away from the carotid pulse. If cannulation is unsuccessful, withdraw the

needle to the skin and redirect it slightly toward the carotid artery.

Once the approach is chosen, slowly advance the needle toward the IJ vein. Create gentle negative pressure with the syringe while advancing the needle. Once blood is seen, stop advancing the syringe. Remove the syringe from the needle to determine whether the vessel is pulsatile. Be careful to not allow negative intrapleural pressure to draw air into the venous system through the open needle. Because the tip of the introducer needle is beveled, lateral motions of the needle tip may cause lacerations of the deep structures of the neck. It is therefore very important to remove the needle from the neck completely before any redirection of the needle.

Once cannulation of the IJ vein has been confirmed, remove the syringe from the needle and place a gloved digit over the needle hub to prevent air embolism. Insert a guidewire through the needle into the IJ vein and place the catheter using the Seldinger technique. Once the wire is inserted into the IJ vein, reduce the angle to the skin to make the needle nearly parallel to the vein. This allows a greater chance of directing the wire toward the heart. Do not let the guidewire extend into the right atrium. The average distance from the insertion site to the junction of the SVC and right atrium is $16 \pm 2$ cm for the right IJ vein and $19 \pm 2$ cm for the left IJ vein. The spring wires supplied in kits are often much longer, up to 60 cm in length. If the full length of the wire is inserted, the wire could enter the right atrium or ventricle and cause myocardial irritability and subsequent dysrhythmias. Monitor cardiac rhythm during insertion of the spring wire to detect cardiac irritability. The distance that the catheter is introduced depends on the distance from the site of introduction to the junction of the SVC and right atrium. This distance will be shorter with the right IJ vein than with the left IJ vein.

### IJ Ultrasound Technique

Cannulation of the IJ vein is an optimal location for the use of ultrasound guidance. Whereas the landmark approach is associated with a complication rate of between 5% and 10% irrespective of the technique used or experience of the operator, with the use of ultrasound, the complication rate is significantly reduced.[101] Even with novice users of ultrasound for IJ vein cannulation, first-attempt success is significantly increased when compared the blind landmark technique, 43% versus 26%.[104] With experience, however, the first-attempt success rate improves to more than 75%.[16,17,105] Use of ultrasound for placement of central lines in the IJ vein has also been shown to decrease overall catheter placement failures by 64%, reduce complications by 78%, and decrease the need for multiple catheter placement attempts by 40% in comparison to the standard landmark placement technique.[106,107] The primary reason for the increased success rate is the variation in anatomy of the IJ vein relative to the carotid artery. The anatomy of the IJ vein has been shown to be aberrant in 9% to 19% of cases.[101,104,107] Furthermore, the IJ vein may be unusually small (i.e., <0.5 cm) in up to 14% of patients. In some patient populations the IJ vein is thrombosed in up to 2.5%.[104]

With the use of ultrasound there is no need for reliance on normal anatomy for cannulation. Therefore, the IJ vein may be cannulated despite abnormal anatomy. Hence, cannulation may occur at the apex of the triangle, near the base at the junction with the innominate vein, or anywhere in between.

## Femoral Approach

### Positioning and Needle Orientation

Place the patient in the supine position for the femoral vein approach. This approach does not require any special positioning or tilting of the bed. Fully expose and thoroughly cleanse the area with a soapy washcloth or surgical scrub brush to remove obvious soiling, which may be more common at this site. Next, prepare the skin at the site broadly with chlorhexidine, including the anterior superior iliac spine laterally and superiorly, extending to the midline, and continuing 10 to 15 cm below the inguinal ligament. Tape a urethral catheter to the contralateral leg. In an obese patient, have an assistant retract the abdominal pannus manually or secure it with wide tape.

After the instillation of local anesthetic, introduce the needle at a 45-degree angle in a cephalic direction approximately 1 cm medial to this point and toward the umbilicus (Fig. 22-16). Palpate the femoral pulse two fingerbreadths beneath the inguinal ligament. Note that while palpating the artery, pressure from the operator's fingers can compress the adjacent vein and impede cannulation. Avoid this anatomic distortion by releasing digital pressure while keeping the fingers on the skin to serve as a visual reference to the underlying anatomy. The depth of the needle required to reach the vein varies with body habitus, but in thin adults, the vein is quite superficial and is usually reached at a depth of approximately 2 to 3 cm. Return of dark, nonpulsatile blood signals successful venous penetration.

Although using the femoral arterial pulse as a guide is ideal, it may not be palpable in an obese or hypotensive patient. A more detailed understanding of the femoral landmarks can be used to guide cannulation attempts. On all but the most
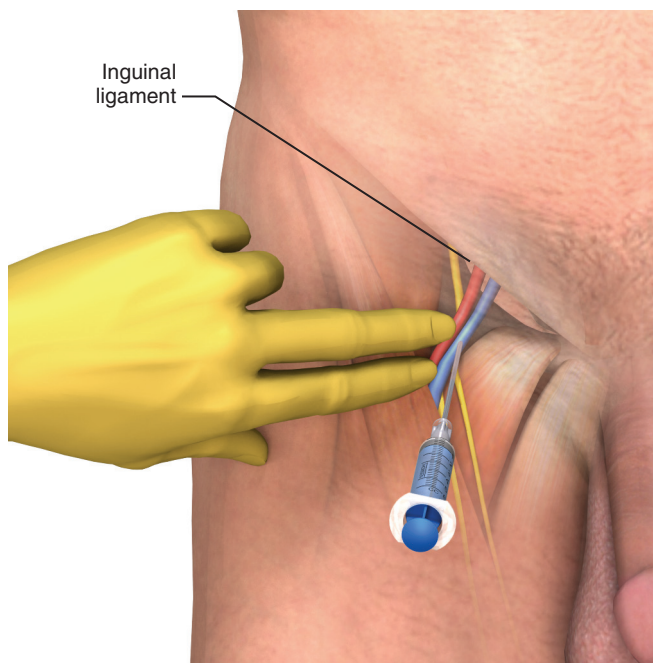


**Figure 22-16** Femoral approach. Palpate the femoral artery two fingerbreadths beneath the inguinal ligament. Introduce the needle at a 45-degree in a cephalic direction 1 cm medial to this point and toward the umbilicus. Importantly, more distally the *vein lies over the artery*, so place the catheter near the inguinal ligament, or use ultrasound guidance.

severely injured trauma patients with a disrupted pelvis (in which case a femoral approach would be contraindicated), the anterior superior iliac spine and the midpoint of the pubic symphysis are easily palpated. The line between these two bony references describes the inguinal ligament. When this line is divided into thirds, the femoral artery should underlie the junction of the medial and middle thirds. The femoral vein will lie approximately one fingerbreadth medial to this point. Alternatively, the vascular anatomy of the region can be evaluated and the line placed via ultrasound guidance.

### Venipuncture

During advancement of the needle, maintain gentle negative pressure on the syringe at all times while the needle is under the skin. Direct the needle posteriorly and advance it until the vein is entered, as identified by a flash of dark, nonpulsatile blood. If the vessel is penetrated when the syringe is not being aspirated, the flash of blood may be seen only as the needle is being withdrawn. The femoral vein lies just medial to the femoral artery at the level of the inguinal ligament. It is closer to the artery than many clinicians appreciate. As the vein progresses distally in the leg, it runs closer to and almost behind the femoral artery.

### Femoral, Ultrasound Technique

Cannulation of the femoral vein under ultrasound guidance is very similar to that for the IJ vein. Using ultrasound, the common femoral vein, its junction with the saphenous vein, and the branches of the common femoral vein—the superficial and deep femoral veins—are easily identified. Typically, placement of the catheter should occur proximal to the bifurcation of the common femoral vein and preferably proximal to the junction with the saphenous vein.

## AFTERCARE

## Anchoring the Central Line

After the central venous catheter is placed, it will need to be anchored in place by one of three techniques: StatLock, suture, or staple (Fig. 22-17). The StatLock may not hold well in patients with oily skin but is excellent for older patients with thin skin. For suturing, one will need the sterile, nonabsorbable suture material (usually 2-0 silk) provided in the CVC kit. The straight suture needles found in many sets are awkward for many clinicians, so a curved needle with a driver may be helpful. To avoid a needlestick with

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### ULTRASOUND: Central Venous Catheterization                    by Christine Butts, MD

**IJ Vein**

When evaluating the internal jugular (IJ) vein, the transducer (7.5 to 20 MHz) should be initially placed over the right or left side of the neck to evaluate the anatomy. An ideal initial location to begin is at the apex of the triangle formed by the two heads of the subclavian muscle (Fig. 22-US1). Placing the transducer over this area in the transverse orientation will enable the vessels to be located in cross section, where they can best be evaluated. The internal carotid artery and IJ vein will be seen as paired structures with anechoic central areas (Fig. 22-US2). The position of one relative to the other can be variable, but typically the IJ lies lateral and superficial to the carotid. Several characteristics of the IJ serve to distinguish it from the carotid. The IJ is typically more oval in shape (versus the rounded shape of the carotid), is thinner walled, and will

compress with gentle pressure. Additionally, the size of the IJ will change with respiration and should be seen to increase in size with a Valsalva maneuver.

Complications can be reduced by several methods. First is to ensure that the target vessel is indeed the vein and not the artery. Variant anatomy or variations in volume status (either depletion or overload) may make the vessels difficult to distinguish from one another. Confirmation should be attempted by noting multiple characteristics of the vessel (compressibility, shape, anatomic location, etc). Once the vessel has
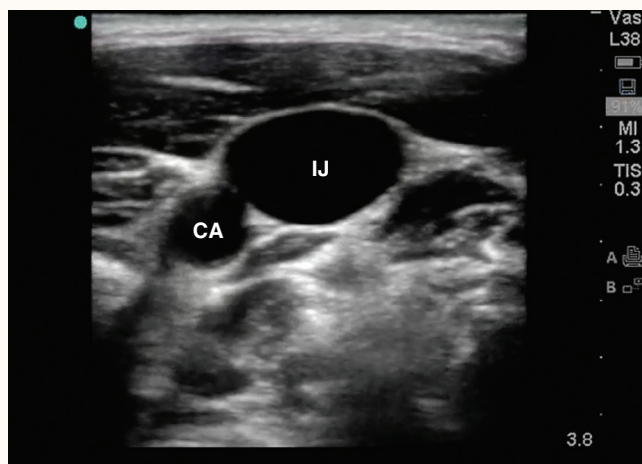


**Figure 22-US1**  Placement of the ultrasound transducer at the apex of the triangle formed by the heads of the sternocleidomastoid.



**Figure 22-US2**  Transverse image of the carotid artery (CA) and internal jugular (IJ) vein. The IJ can be recognized by its oval or triangular shape, its thinner walls, and collapse with light pressure. Although both are rounded and contain anechoic (*black*) fluid, the IJ is slightly larger and more oval in shape. Though not evident in this image, slight pressure will cause collapse of the IJ.

*Continued*

## ULTRASOUND: Central Venous Catheterization, cont'd

been confirmed as the vein, the operator must take great care to ensure that the position of the tip of the needle is apparent at all times. Most complications occur when the tip of the needle is deeper or more medial than the operator realizes, thus placing it in proximity to other structures (e.g., lung, carotid artery). An extensive discussion of each approach can be found in the basic ultrasound chapter (see Chapter 66), and each approach has its drawbacks in determining position. In the transverse method, the angle of approach can be difficult to ascertain and cause the tip of the needle to be deeper than the operator realizes. Additionally, the tip of the needle may be difficult to follow. In the longitudinal approach, the medial to lateral orientation of the needle can be difficult to appreciate. Additionally, slight movements of the transducer may result in loss of the appropriate image. A combination of these two, or an oblique approach, may minimize these difficulties.

### Femoral Vein

The femoral artery and vein lie together with the femoral nerve within a common sheath. They can be found at the level of the inguinal crease on the medial aspect of the thigh. Palpating the femoral pulse will also aid in localizing the vascular bundle. The transducer (7.5 to 10 MHz) should be placed in a transverse or slightly oblique orientation overlying this area. Slightly externally rotating the thigh may facilitate this step. Classically, the artery is described to lie lateral to the vein. However, this is often not the case and multiple variations may be noted. The femoral artery and vein will appear as rounded anechoic structures (Fig. 22-US3). The femoral vein can be recognized by its thinner walls, slightly more oval shape, and collapse with gentle pressure. It will also typically increase in size when the lower part of the leg is squeezed. The vascular bundle may need to be followed inferiorly or superiorly to determine the most optimal location for puncture.

Complications can be reduced by several methods. First is to ensure that the target vessel is indeed the vein and not the artery. Variant anatomy or variations in volume status (either depletion or overload) may make the vessels difficult to distinguish from one another. Confirmation should be attempted by noting multiple characteristics of the vessel (compressibility, shape, anatomic location, etc). Once the vessel has
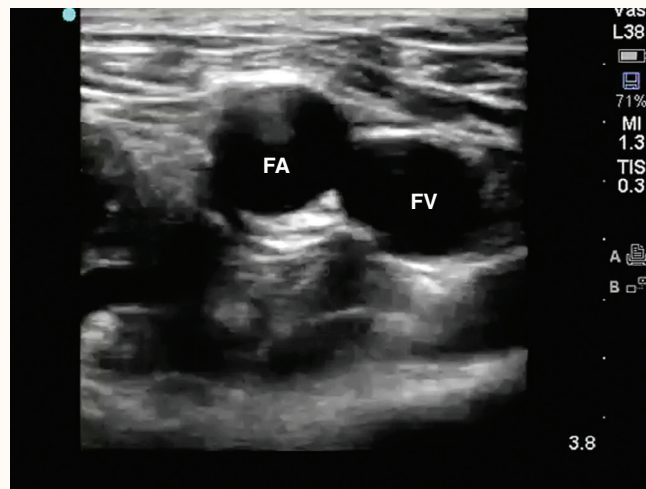
been confirmed as the vein, the operator must take great care to ensure that the position of the tip of the needle is apparent at all times. The tip of the needle may be difficult to follow in the transverse approach and result in an inadvertent puncture of the posterior wall of the vessel. When the artery lies deep to the vein, arterial puncture or cannulation may result. In the longitudinal approach, the medial to lateral position of the needle may be difficult to appreciate and result in accidental arterial puncture. The oblique approach may minimize these difficulties.

### Subclavian Vein

The subclavian vessels can be imaged from either a supraclavicular or an infraclavicular approach. For the supraclavicular approach, the transducer (7.5 to 10 MHz) is placed along the long axis of the clavicle on the superior aspect (Fig. 22-US4). It should be angled downward. In this view the vessels should be seen in their long axis (Fig. 22-US5). The vein can be identified by its variation with respiration and change in size



**Figure 22-US4** Placement of the ultrasound transducer superior to the clavicle to enable visualization of the subclavian vessels in the long axis.



**Figure 22-US3** Transverse image of the femoral artery (FA) and femoral vein (FV). Similar to vessels in the neck, the femoral vein is more oval or triangular in shape. Though not evident in this image, slight pressure will cause collapse of the vessel.
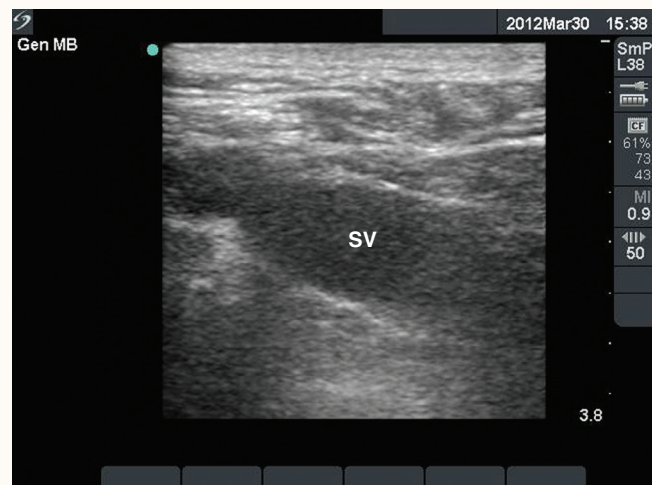


**Figure 22-US5** Long-axis view of the subclavian vein. The subclavian artery, not seen in this image, will be seen as a similar-appearing vessel deep to the vein. Color flow and Doppler can be used to distinguish between the two vessels.

## ULTRASOUND: Central Venous Catheterization, cont'd

with the Valsalva maneuver. The vein can also be followed to identify the junction with the IJ vein, thereby offering further confirmation. In the infraclavicular approach, the transducer is placed beneath the clavicle at its most lateral aspect, in a sagittal or slightly oblique orientation, following the position of the clavicle (Fig. 22-US6). In this view the vessels will be seen in cross section or a slightly oblique plane (Fig. 22-US7). The pleura may also be seen deep to the vessels as an echogenic vertical line that slides back and forth with respiration.

A longitudinal approach should be used in which the needle is introduced from the end of the transducer in either the infraclavicular or the supraclavicular approaches. This will enable a shallow angle to be used and thereby minimize the chance of damaging deeper structures such as the lung. Once a flash of blood has been obtained, the ultrasound transducer can be set aside and the procedure continued as described above.

The subclavian artery and vein lie in close opposition to the pleura, so pneumothorax is a more common complication. Using a long-axis approach (in which the needle is introduced from the end of the transducer rather than from the middle) offers the advantage of visualizing the entirety of the needle in its course toward the vein. A shallow angle can be used, and the relationship of the needle to the pleura can also be appreciated.
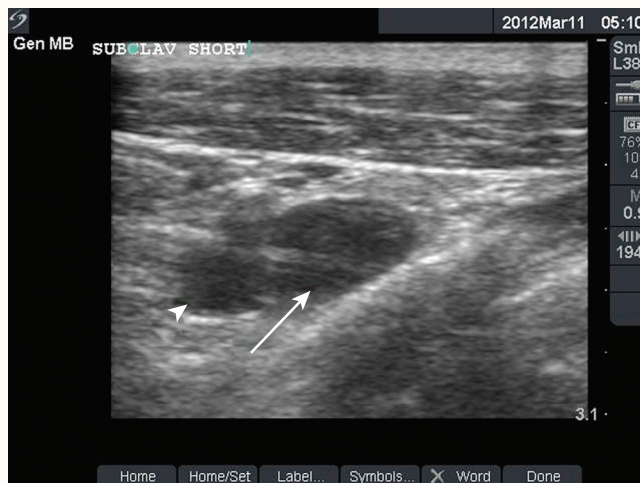


**Figure 22-US6**  Placement of the ultrasound transducer inferior to the clavicle to enable visualization of the subclavian vessels in short axis. A sagittal (shown) or slightly oblique orientation should be used.



**Figure 22-US7** Short-axis view of the subclavian artery (*arrowhead*) and vein (*arrow*) as seen from the inferior aspect of the clavicle.

the straight needle, pass the blunt end of the needle through the anchoring devices and pull the suture forward manually. Place the suture in the skin approximately a half centimeter from the catheter to anchor the central line in place. Several knots should be made to secure the line. Avoid making knots that place excessive pressure on the skin because this can lead to difficulty removing the knots and necrosis. Loose knots can lead to migration of the catheter and loss of access. Stapling a central line into place can be just as effective as suturing; however, the staples tend to fall out after a few days.

### Dressing

Clean the area around the catheter insertion site with chlorhexidine, and then use a clear dressing (such as Tegaderm) to cover up the insertion site of the catheter once secured (see Fig. 22-9, *step 16*). Apply a chlorhexidine patch (Biopatch) at the site where the catheter enters the skin (see Fig. 22-17E and F). Because dressings are inspected and changed periodically, place a simple dressing and avoid excessive amounts of gauze and tape. Take care to protect the skin against maceration.

### Assessing Line Placement

Check all tubing and connections for tightness to prevent air embolism, loss of fluid, or bleeding. Before infusing IV fluids, lower the IV fluid reservoir to below the level of the patient's right atrium and check the line for backflow of blood. Free backflow of blood is suggestive but not diagnostic of intravascular placement. Backflow could occur from a hematoma or hemothorax if the catheter is free in the pleural space. A pulsatile blood column may be noted if the catheter has been inadvertently placed in an artery. Less pronounced pulsations might also occur if the catheter is advanced too far and reaches the right atrium or ventricle. In addition, pulsations may be noted with changes in intrathoracic pressure as a result of respirations, although these pulsations should occur at a much slower rate than the arterial pulse. A final method of checking intravascular placement is to attach a syringe directly to the catheter hub and aspirate venous blood. It is also advisable to ensure that the catheter is easily flushed with a saline solution. This carries the additional benefit of removing air from the system. Radiographs are also always indicated to verify catheter location and assess for potential complications, except after routine femoral line placements. In an awake

## SECURING A CENTRAL VENOUS CATHETER
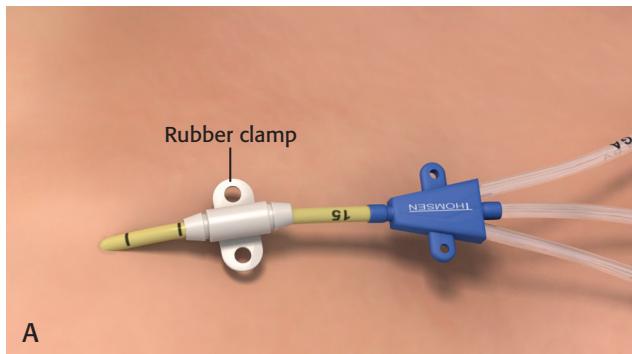


A white rubber clamp is provided to secure the catheter when the full length is not needed. Twist open the pliable clamp and place it over the catheter at a site a few centimeters from the insertion site.
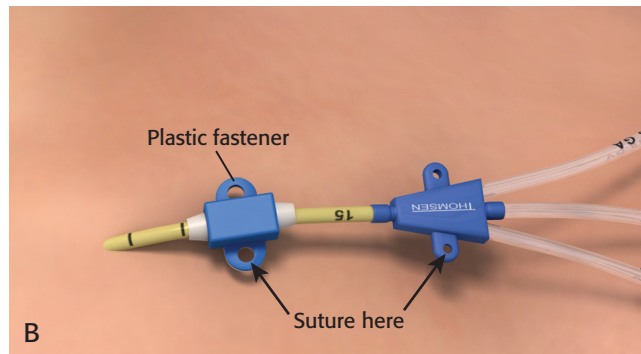
The rubber clamp is covered with a blue plastic fastener, and both the clamp and fastener are sutured to the skin to secure the catheter. The hub of the catheter is also sutured to the skin.
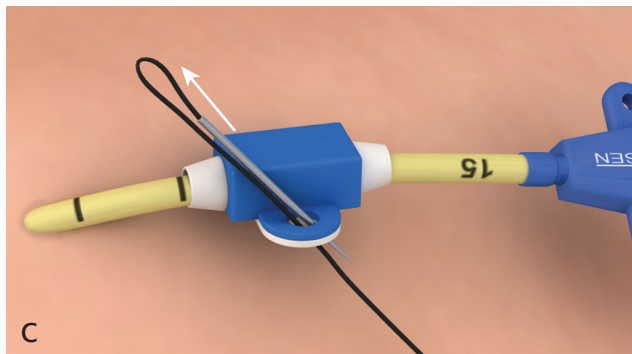
To avoid a needlestick, the blunt end of the needle is used to pass the suture through the holes of the fastening devices.
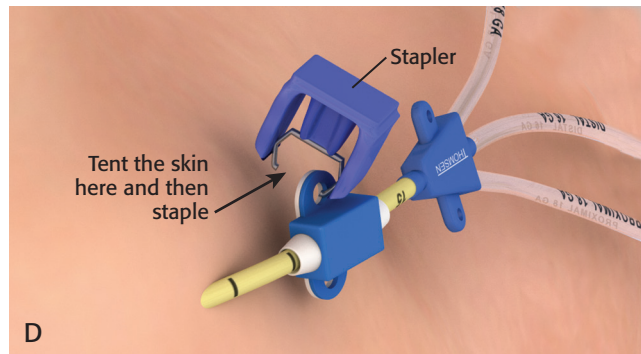
Alternatively, skin staples may be used. Tent the skin and pass the staples through the anchoring eyes.
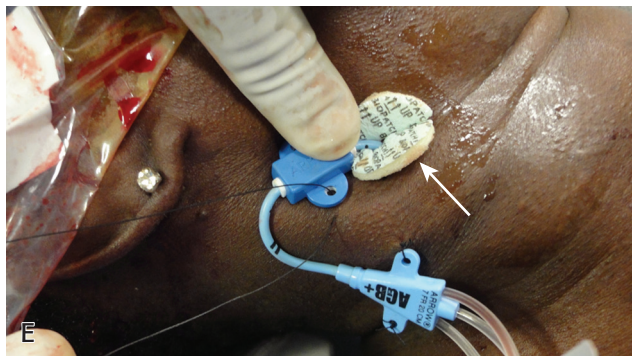
This Biopatch is a chlorhexidine-containing hydrophilic covering placed at the site where the catheter enters the skin to deliver local antisepsis for 7 days.
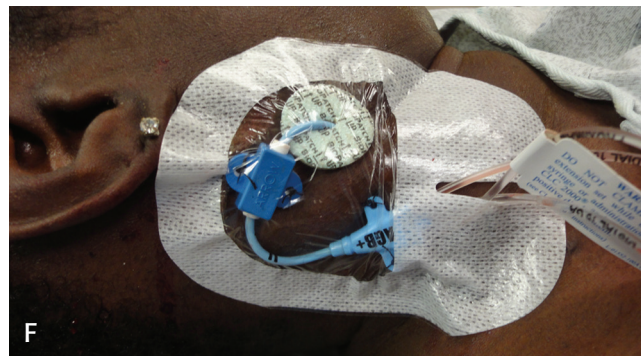
A simple Tegaderm clear covering is then applied.

**Figure 22-17** Methods to secure a central venous triple-lumen catheter.

patient, infusing fluids via a catheter tip positioned in the IJ vein may produce an audible gurgling or flowing sound in the patient's ear.[108]

### Radiographs

Following placement of lines involving puncture of the neck or thorax, listen to the lungs to detect any inequality of lung sounds suggestive of a pneumothorax or hemothorax. Obtain a chest film as soon as possible to check for hemothorax, pneumothorax, and the position of the tip of the catheter (Fig. 22-18). Because small amounts of fluid or air may layer out parallel to the radiographic plate with the patient in the supine position, take the film in the upright or semi-upright position whenever possible. In ill patients, a rotated or oblique projection on a chest radiograph may be obtained, and the clinician may be confused about the proper position of the catheter. In such cases, repeat the radiograph. A misplaced catheter tip is usually obvious on a properly positioned standard posteroanterior chest radiograph (Fig. 22-19), but
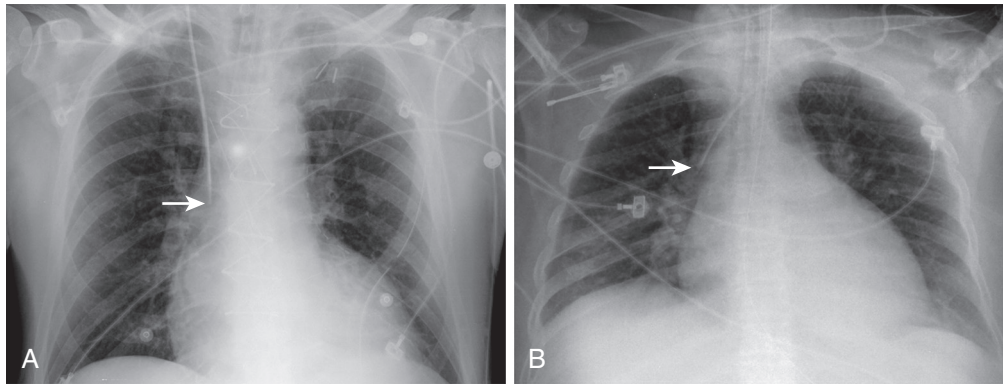
**Figure 22-18** Chest radiographs obtained after placement of right internal jugular (**A**) and left subclavian (**B**) central venous catheters. The tips of the catheters are appropriately placed in the superior vena cava (*arrows*). The tip should not lie within the right atrium or the right ventricle.
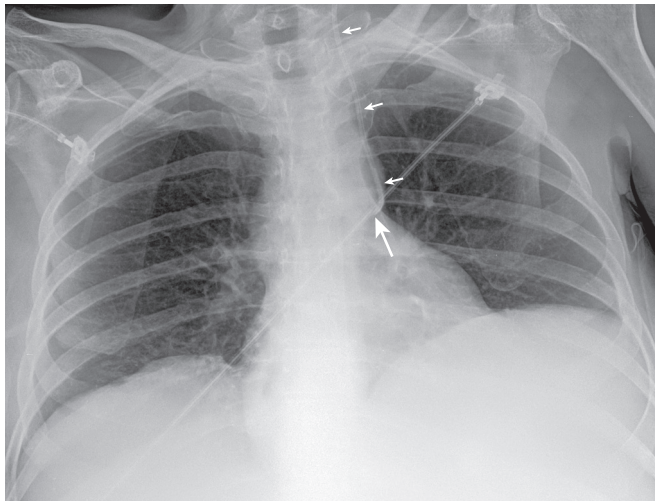


**Figure 22-19** Chest radiograph obtained after left internal jugular catheterization. Note that the course of the catheter (*small arrows*) does not cross the midline and that the tip (*large arrow*) projects to the left of the midline near the aortic arch. Although the catheter may have been located intravascularly in a venous anatomic variant, it was decided to remove this line and replace it with a new catheter.

occasionally, injection of contrast material may be required. For example, a catheter in one of the internal thoracic veins may simply appear more lateral than expected, but because of the close proximity of these veins and the SVC, malposition may not be appreciated by this subtle finding. Misplaced catheters should be repositioned or replaced.

Attention should also be given to the possibility of a retained guidewire. Although this complication is rare, if not specifically considered it can be overlooked by both clinicians and radiologists.[109,110]

Postprocedure radiographs are not always necessary for routine replacement of catheters over guidewires. If such patients are stable and being hemodynamically monitored, radiography may be deferred safely in the absence of apparent complications or clinical suspicion of malposition.[111,112]

### Redirection of Misplaced Catheters

Improper catheter tip position occurs commonly. It has been reported that only 71% of SV catheters are located in the

SVC on the initial chest film. Complications of improper positioning include hydrothorax, hemothorax, ascites, chest wall abscess, embolization to the pleural space, and chest pain. More commonly, improper location yields inaccurate measurements of CVP or is associated with poor flow caused by kinking. An unusual complication attributable to improper tip position is cerebral infarction, which can occur following inadvertent cannulation of the subclavian artery.

Misdirection or inappropriate positioning of the tip of a CVC, when promptly recognized and corrected, is an inconsequential complication. Loop formation, lodging in small neck veins, tips directed caudally, and innominate vein position are common problems. Reposition misplaced catheters as soon as logistically possible. If the catheter is being used for fluid resuscitation, the malposition may be tolerated for some time. If vasopressors or medications are infused, proper positioning of the tip of the catheter is more critical. A number of options are available to remedy malpositioning. One strategy is to insert a 2-Fr Fogarty catheter through the lumen of the central line and advance it 3 cm beyond the tip. Withdraw the entire assembly until only the Fogarty catheter is in the SV. Inject 1 mL of air into the balloon, and advance the Fogarty catheter. It is hoped that blood flow will direct the assembly into the SVC. Deflate the balloon and advance the central line over the Fogarty catheter, which is then withdrawn.

Another anecdotal strategy is to withdraw the catheter until only the distal tip remains in the cannulated vessel. This measurement is best appreciated by comparing the length of the indwelling catheter with another unused catheter. The clinician then simply readvances the catheter in the hope that it becomes properly positioned. Other manipulations with guidewires have been suggested, but reinsertion with another puncture is often required for the misplaced catheter to be positioned properly. This approach also decreases the risk for infection by avoiding the introduction of bacteria into the vessel from any nonsterile segment of the CVC.

## SPECIAL CONSIDERATIONS FOR OTHER VESSELS

### External Jugular Vein Approach

Central venous catheterization via the external jugular vein is time-consuming and often difficult. The difficulty in converting an external jugular catheter into a CVC frequently

renders it a lower-yield clinical procedure. Use of the external jugular vein for achieving central venous access requires that a guidewire be used. After cannulation of the vein and intraluminal placement of the guidewire, advance the guidewire into the thorax by rotating and manipulating the tip into the central venous circulation. Advancement of the guidewire is the most difficult and time-consuming portion of the procedure, and the time requirement limits the usefulness of this technique in an emergency. A small-radius J-tipped wire, a distended vessel lumen, and exaggeration of patient head tilt, coupled with skin traction, may facilitate successful passage of the guidewire. Partially withdrawing the wire and twisting it 180 degrees before readvancing the tip may also be helpful.

## Basilic and Cephalic Approaches

Passing a catheter into the central circulation is difficult via the basilic and cephalic routes, and failure is common. Insertion of a peripheral IV central catheter through these routes is often performed by specialized teams and is less suitable for emergency indications. The cephalic vein may terminate inches above the antecubital fossa or bifurcate before entering the axillary vein and send a branch to the external jugular vein. The cephalic vein may also enter the axillary vein at a right angle, thereby defeating any attempt to pass the catheter centrally. Furthermore, both the basilic and the cephalic systems contain valves that may impede catheterization. Abduction of the shoulder may help advance the catheter if resistance near the axillary vein is encountered. The incidence of failure to place the catheter in the SVC ranges from a high of 40% to a low of 2%.[44,113] The greatest success rate (98%) reported was obtained with slow catheter advancement and the patient in a 45- to 90-degree upright position.[44] A flexible catheter was introduced into the basilic vein until the tip was judged to be proximal to the junction of the cephalic and basilic veins and distal to the junction of the IJ vein with the innominate vein. The wire stylet was withdrawn 18 cm, and the catheter was advanced slowly 1 cm at a time, with 2 seconds allowed between each 1-cm insertion. The natural flexibility of Bard catheters contributed to negotiation into the SVC when the patient was upright. This time-consuming technique is contraindicated when the patient cannot tolerate an upright position.

The basilic and cephalic venous systems are entered through the large veins in the antecubital fossa. Placement of a tourniquet aids venous distention and initial venous puncture. When veins are not visible, they may be identified with bedside ultrasound (as described in Chapter 66). The basilic vein, located on the medial aspect of the antecubital fossa, is generally larger than the radially located cephalic vein. Furthermore, the basilic vein usually provides a more direct route for passage into the axillary vein, SV, and SVC.

## Vascular Access in Cardiac Arrest

Immediate vascular access is required for resuscitation during cardiac arrest. Femoral CVCs are often used in this setting. The infraclavicular SV approach is also commonly used during cardiac arrest if logistics permit. The intuitive rationale for femoral CVC placement has been that much of the resuscitation activity, including chest compressions, occurs on the thorax, thus limiting the clinician's ability to safely place a higher line. During cardiac arrest, the availability of drugs delivered to the central circulation may be slower via the femoral route than via supraclavicular SV or IJ vein infusions.[113,114] Additionally, pulsations felt in the groin during CPR may be venous instead of arterial,[28] and there is a high rate of unrecognized catheter malposition and arterial injury.[28,115] To place a femoral catheter blindly (without ultrasound guidance or clear identification of the arterial pulse), divide the distance from the anterior superior iliac spine to the symphysis pubis into thirds. The artery typically lies at the junction of the medial and middle thirds and the vein 1 cm medial to this location. Blind femoral central line insertions during arrest are less than optimal. The increasingly available intraosseous placement systems and bedside ultrasonography are beginning to supplant such "blind" CVC placements during cardiac arrest and other emergencies that require immediate vascular access.

## CVP MONITORING

### CVP Measurement

Although described by Forssman in 1931, it was not until the early 1960s that measurement of CVP became commonplace as a means of assessing cardiac performance and guiding fluid therapy.[10] CVP measurements are most frequently used as a guide for determination of a patient's volume status and fluid requirements and for investigation of tamponade.[116] CVP monitoring has often been criticized as ineffective, outmoded, and unreliable,[117] but in the last few years a resurgence in its use has occurred.[118] Astute clinicians can maximize the usefulness of this diagnostic tool by understanding its basic principles, indications, and limitations.[119-121]

### Physiology

Simply stated, CVP is the pressure exerted by blood against the walls of the intrathoracic venae cavae. Because pressure in the great veins of the thorax is generally within 1 mm Hg of right atrial pressure, CVP reflects the amount of blood or pressure at which blood is returning to the heart. Pressure in the central veins has two significant hemodynamic effects. First, the pressure promotes filling of the heart during diastole, a factor that helps determine right ventricular enddiastolic volume (preload). Second, CVP is also the backpressure of the systemic circulation and opposes return of blood from peripheral blood vessels into the heart. CVP is therefore a measure of both the ability of the heart to pump blood (cardiac function) and the tendency for blood to flow from the peripheral veins (venous return to the heart). The CVP reading is determined by a complex interaction of intravascular volume, right atrial and ventricular function, venomotor tone, and intrathoracic pressure.[116,117,119,120]

To measure CVP, place the tip of a pressure-monitoring catheter into any of the great systemic veins of the thorax or into the right atrium.[119,121] You can also use the femoral vein for measurement as long as there is no evidence of increased abdominal pressure.[10,122] The catheter is connected to a simple manometer or to an electronic pressure transducer interfaced with a monitoring system, at the level of the right atrium, that is capable of calculating a mean pressure value and displaying pressure waveforms.[119,121] The waveforms produced correlate with the cardiac cycle and create a typical wave pattern.

## Central Venous Pressure Measurement

### Indications
Acute circulatory failure
Anticipated massive blood transfusion or fluid
  replacement therapy
Cautious fluid replacement in patients with
  compromised cardiovascular status
Suspected cardiac tamponade
Fluid resuscitation during goal-directed therapy
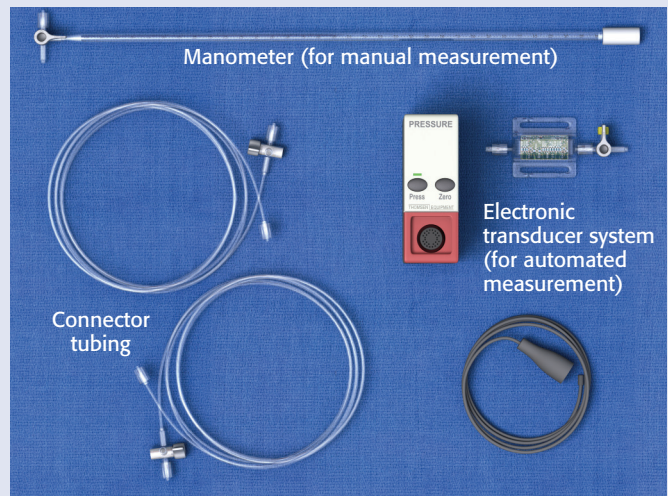  for severe sepsis

### Contraindications
Other resuscitative interventions that take priority over
  central venous access and central venous pressure setup
Large vegetations on the tricuspid valve
Superior vena cava syndrome
Right atrial tumor or thrombus

### Complications
Faulty central venous pressure readings:
  Increased intrathoracic pressure (ventilator, straining, coughing)
  Failure to calibrate or zero the transducer
  Malposition of the tip of the catheter
  Obstruction of the catheter
  Air bubbles in the circuit
  Readings during the wrong phase of ventilation
  Vasopressors (presumed)

### Equipment



Manometer (for manual measurement)

Electronic transducer system (for automated measurement)

Connector tubing

**Review Box 22-2** Central venous pressure measurement: indications, contraindications, complications, and equipment.

## Indications for and Contraindications to CVP Measurement

The five traditional major indications for monitoring CVP are:

1. Acute circulatory failure
2. Anticipated massive blood transfusion or fluid replacement therapy
3. Cautious fluid replacement in patients with compromised cardiovascular status
4. Suspected cardiac tamponade
5. Fluid resuscitation during goal-directed therapy in patients with severe sepsis

The procedure is contraindicated when other resuscitative therapeutic and diagnostic interventions take priority over central venous access and CVP transducer setup and calibration or in the setting of large vegetations on the tricuspid valve, SVC syndrome, or tumors or thrombus in the right atrium.

A common misconception is that CVP consistently reflects pressure in the left side of the heart. The measurement that best reflects changes in left ventricular pressure and reserve is left atrial pressure or the nearly equivalent pulmonary capillary wedge pressure (PCWP). Development of the flow-directed pulmonary artery catheter has allowed repeated measurements of PCWP, thus permitting reliable estimation of left atrial pressure.[121]

CVP monitoring is most helpful in patients without significant preexisting cardiopulmonary disease. Numerous studies highlight the unreliability of right-sided hemodynamic monitoring in patients with underlying cardiac or pulmonary disease.[111,115] Ultimately, however, the differences noted are not a failure of CVP monitoring to reflect central hemodynamics. Rather, the disagreements noted by previous authors simply highlight the complexity of the relationship between ventricular and vascular compliance, blood volume, and filling pressure in various disease states. As with pulmonary artery occlusion pressure measurements, the clinician is cautioned to be aware of the assumptions involved and to recognize the scenarios in which these assumptions do not hold true.

## Procedure

Although CVP may be determined with a manometry column assembled at the bedside (Fig. 22-20), the most common technique in practice is measurement with an electronic transducer interfaced to a monitoring system (Fig. 22-21). Typical transducers include a nipple valve attached to a pressurized bag of saline to allow easy flushing of the system. To use these manometers, attach the transducer to the patient's central line with a length of flexible, yet fairly rigid-walled tubing filled with saline. Place a three-way stopcock between the patient and the transducer to simplify line flushing and calibration.

Flush all air bubbles from the system by opening the stopcock to air and flushing saline through the line. Do not flush air bubbles into the patient. Even tiny bubbles left in the tubing will dampen the CVP wave and potentially cause underestimation of venous pressure.

## MEASUREMENT OF CENTRAL VENOUS PRESSURE: MANOMETRY

**1**
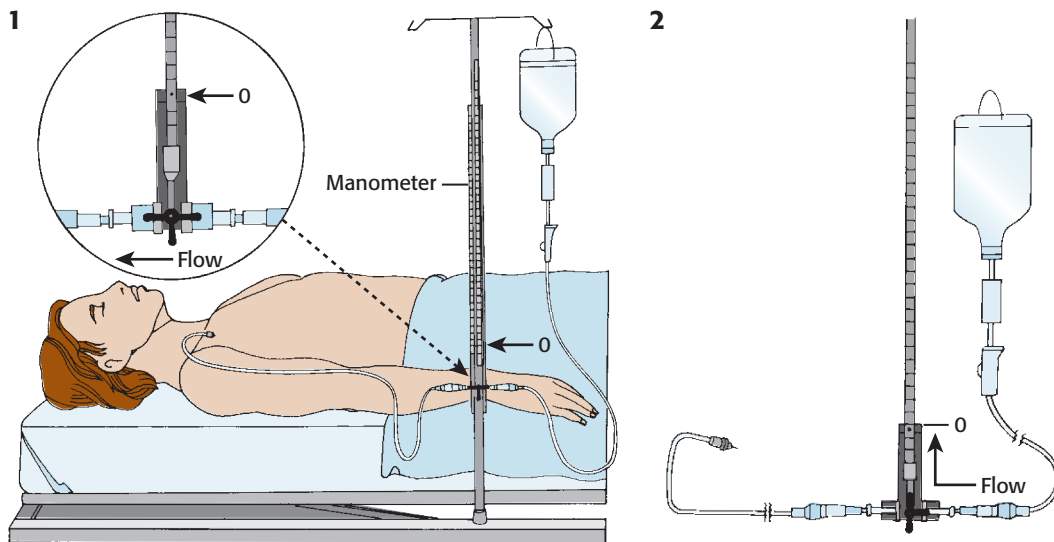
Assemble the manometer as depicted above. When the stopcock is turned to direct flow of fluid to the patient, the manometer is bypassed. This is the position that is maintained to keep the catheter patent. Remember to always flush all tubing before connecting it to the patient's central catheter.

**2**

To measure central venous pressure, first turn the stopcock to fill the manometer to 25 cm $H_2O$.

**3**
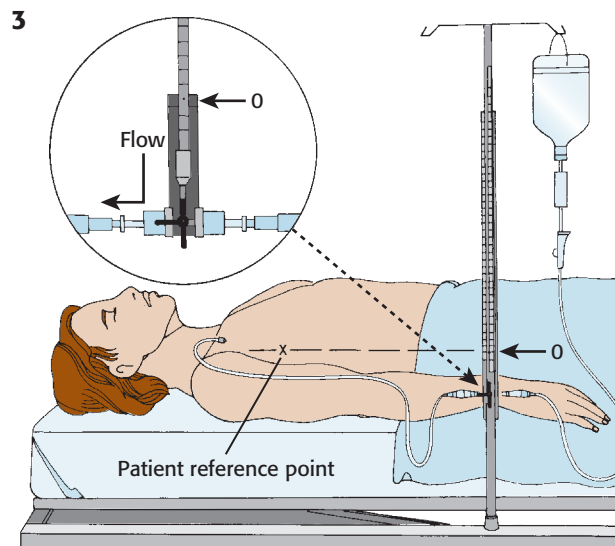
Next, open the stopcock to the patient and the manometer. Allow the column of water in the manometer to fall and stabilize before a reading is taken. Note that the zero mark must be horizontally aligned with the tricuspid valve (which is estimated as the midaxillary line in a supine patient).

**Figure 22-20** Measurement of central venous pressure with a manual manometer.

After the system has been flushed, place the stopcock (with the transducer still open to air) at the level of the patient's right atrium. Zero (calibrate) the monitor detecting the transducer's signal with the transducer at the level of the right atrium, which can be approximated on the skin surface as a point at the midaxillary line and the fourth intercostal space.[119,121] Finally, set the stopcock so that the transducer is in continuity with the patient's venous catheter.

In spontaneously breathing patients, take readings at the end of a normal inspiration. If the patient is receiving positive pressure ventilation, the changes in CVP during the respiratory cycle are reversed: it rises with inspiration and decreases with expiration. In these patients, take readings near the end of expiration.[121] Thus, during both normal and mechanical ventilation, the lowest reading is a useful estimate of mean CVP.

## MEASUREMENT OF CENTRAL VENOUS PRESSURE: TRANSDUCER

**1** Insert a bag of normal saline into a pressure bag and inflate to the recommended pressure (usually 300 mm Hg).

**2** Flush all air bubbles from the system by opening the stopcock and running saline through the line. Any air left in the system will cause erroneous CVP readings. Take care to not flush air into the patient.

**3** Connect the flushed transducer tubing to the patient's central line.

**4** Mount the transducer at the level of the patient's right atrium. This level can be approximated on the skin surface as a point at the midaxillary line and fourth intercostal space.

Transducer at level of right atrium
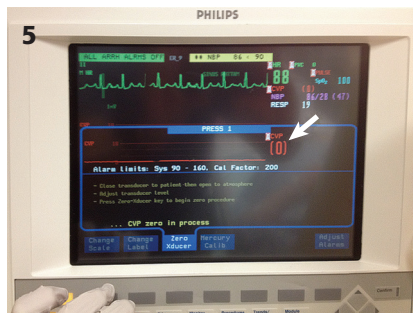
**5** Adjust the stopcock so that the transducer is open to air, and zero the system. The exact process for the zeroing procedure will vary by the equipment manufacturer.
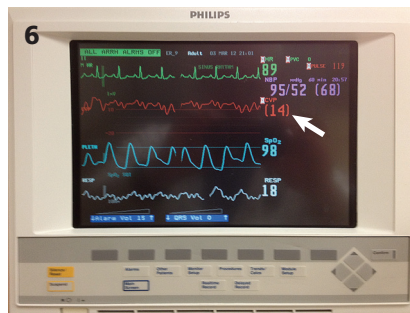
**6** Finally, set the stopcock so that it is open to the transducer and the central venous catheter. Observe for a venous waveform and CVP reading on the monitor (*arrow*).

**Figure 22-21** Measurement of central venous pressure (CVP) with an electronic transducer.

Take a reading after accurate placement of the tip of the catheter has been established. To ensure optimal measurement, place the patient in the supine position. Whenever the patient is repositioned, take care to ensure that the transducer has been recalibrated to reflect the new position of the patient.

### Errors in CVP Measurement

A number of extrinsic factors may alter the accuracy of the CVP reading (Box 22-1).[116,119,121] In addition to the position of the patient, such factors include changes in intrathoracic pressure, malposition of the tip of the catheter , obstruction of the catheter, and failure to calibrate or zero the line. Activities that increase intrathoracic pressure, such as coughing or straining, may cause spuriously high measurements. Make sure that the patient is relaxed at the time of measurement and breathing normally. In mechanically ventilated patients, CVP will be elevated to an extent directly proportional to the ventilatory pressure being delivered and inversely proportional to the mechanical compliance of the lung. Care should be exercised in interpreting filling pressure in this circumstance because ventilator-induced elevations in CVP are not

| BOX 22-1 | Reasons for Faulty CVP Readings |
| --- |

Increased intrathoracic pressure (ventilator, straining, coughing)
Failure to calibrate or zero the transducer
Malposition of the tip of the catheter
Obstruction of catheter
Air bubbles in the circuit
Readings during the wrong phase of ventilation
Vasopressors (presumed)

CVP, *central venous pressure.*

artifactual but represent changes in the hemodynamic physiology of the patient. As in spontaneously breathing patients, CVP measurements are meaningful only in relaxed, sedated, or paralyzed subjects.

Another reason for faulty readings is malposition of the tip of the catheter. If the catheter tip has not passed far enough into the central venous system, peripheral venous spasm or venous valves may yield pressure readings that are inconsistent with the true CVP.

If the tip of the catheter has passed into the right ventricle, a falsely elevated CVP measurement is obtained. Recognition of a characteristic right ventricular pressure waveform on the patient's monitor should hopefully preclude this error. Such fluctuations may also occasionally be seen in appropriately positioned CVP lines when significant tricuspid regurgitation or atrioventricular dissociation (a cannon "a" wave) is present.[117] Inaccurate low venous pressure readings are seen when a valvelike obstruction at the tip of the catheter occurs as a result of either clot formation or contact against a vein wall. Wave damping secondary to air bubbles in the transducer or tubing also leads to faulty readings. Using poorly zeroed lines may result in inaccurate measurements that may be interpreted as a change in the patient's status when none has actually taken place. The transducer should be zeroed to the same level for every measurement.

## Interpretation of CVP Measurement

Normal CVP values are as follows:

Low: <6 cm $H_2O$
Normal: 6 to 12 cm $H_2O$
High: >12 cm $H_2O$

In the late stages of pregnancy (30 to 42 weeks), CVP is physiologically elevated, and normal readings are 5 to 8 cm $H_2O$ higher. A CVP reading of less than 6 cm $H_2O$ is consistent with low right atrial pressure and reflects a decrease in the return of blood volume to the right heart. This may indicate that the patient requires additional fluid or blood. A low CVP reading is also obtained when vasomotor tone is decreased, as with sepsis, spinal cord injury, or other forms of sympathetic interruption.

A CVP reading falling within a normal range is viewed in relation to the clinical scenario. A reading higher than 12 cm $H_2O$ indicates that the heart is not effectively circulating the volume presented to it. This may occur in a normovolemic patient with underlying cardiac disease such as left ventricular hypertrophy (with associated poor ventricular compliance) or in a patient with a normal heart who is volume-overloaded. High CVP can also be related to variables other than pump failure, such as pericardial tamponade, restrictive pericarditis, pulmonary stenosis, tricuspid regurgitation, pulmonary hypertension, and pulmonary embolism.[123]

Changes in blood volume, vessel tone, and cardiac function may occur alone or in combination with one another; therefore, it is possible to have a normal or elevated CVP in the presence of normovolemia, hypovolemia, and hypervolemia.[123] Interpret the specific CVP values with respect to the entire clinical picture. The response of CVP to an infusion is more important than the initial reading.

## Fluid Challenge

Monitoring CVP may be helpful as a practical guide to fluid therapy.[116,118-121] Serial CVP measurements provide a fairly reliable indication of the capability of the right side of the heart to accept an additional fluid load. Although PCWP is a more sensitive index of left heart fluid needs (and in some clinical situations measurement of PCWP is essential), serial measurement of CVP can nonetheless provide useful information.

A fluid challenge can help assess both volume deficits and pump failure.[120] Although a fluid challenge can be used with either PCWP monitoring or CVP monitoring, only the fluid challenge for CVP monitoring is discussed here. Slight variations in the methodology of fluid challenge are reported in the literature. Generally, fluid boluses of 250 to 500 mL of crystalloid are administered sequentially and CVP is measured 10 minutes after each bolus. Repeat the fluid challenge until measurements indicate that adequate volume expansion has occurred. Discontinue the fluid challenge as soon as hemodynamic signs of shock are reversed or signs of cardiac incompetence are evident.

## Cardiac Tamponade

In cardiac tamponade, pericardial pressure rises to equal right ventricular end-diastolic pressure. The pericardial pressure encountered in pericardial tamponade characteristically produces an elevated CVP.[123] The degree of elevation in CVP is variable, and one must interpret measurements cautiously; CVP readings in the range of 16 to 18 cm $H_2O$ are typically seen with acute tamponade, but elevations of up to 30 cm $H_2O$ may be encountered. The precise CVP reading is often lower than one might intuitively expect, and it is not uncommon to encounter tamponade with a CVP of 10 to 12 cm $H_2O$. A normal or even low CVP reading may be seen if the tamponade is associated with significant hypovolemia. An excessive rise in CVP after fluid challenge may be more important than a single reading in the diagnosis of pericardial tamponade.

Excessive straining, positive pressure ventilation, agitation, inflation of pneumatic antishock garments, and tension pneumothorax may all increase intrathoracic pressure, produce a high CVP reading, and erroneously suggest the diagnosis of pericardial tamponade. Increases in vascular tone, as seen with the use of dopamine or other vasopressors, may also elevate CVP and thus mimic tamponade and complicate estimations of volume.

## COMPLICATIONS

The medical literature is replete with reports of CVC complications. Understanding the pathophysiology surrounding CVC complications helps clinicians anticipate, recognize, and manage complications should they arise and better educate patients and their families during the informed consent process.

More than 15% of patients who receive CVCs experience some type of complication, and complications occur despite pristine technique.[42,73] This percentage is not surprising in view of the close proximity of vital structures, the complexity of patients' medical conditions, and the emergency circumstances under which many of these procedures are often performed. The number of complications increases, especially those involving thrombosis and infection, with longer durations of catheterization and increasing severity of illness.[25] Although clinicians strive to limit complications, their occurrence cannot naïvely be viewed as evidence of faulty technique or substandard care. Common complications with the different approaches are summarized in Box 22-2 and Table 22-4 and can generally be categorized as mechanical, infectious, and thrombotic. Key complications and injuries by approach are discussed below.

The number of lumens does not directly affect the rate of catheter-related complications.[42,73] One 3-year retrospective

## BOX 22-2 Complications of Central Venous Access

**GENERAL**

**Mechanical**
Puncture of an adjacent artery
Hematoma formation
Air embolus
Pneumothorax
Pericardial tamponade
Catheter embolus
Arteriovenous fistula
Mural thrombus formation
Large-vein obstruction
Dysrhythmias
Catheter knotting
Catheter malposition

**Infectious**
Bloodstream infection
Generalized sepsis
Septic arthritis
Osteomyelitis
Cellulitis at the insertion site

**Thrombotic**
Pulmonary embolism
Venous thrombosis

**SV AND IJ APPROACHES**

**Pulmonary**
Pneumothorax
Hemothorax
Hydrothorax
Chylothorax
Neck hematoma and tracheal obstruction
Endotracheal cuff perforation
Tracheal perforation

**Neurologic**
Phrenic nerve injury
Brachial plexus injury
Cerebral infarct

**FEMORAL APPROACH**

**Intraabdominal**
Bowel perforation
Psoas abscess
Bladder perforation

IJ, *internal jugular*; SV, *subclavian vein.*

## TABLE 22-4 Anatomic Structures That Can Be Injured by Central Venous Cannulation

| STRUCTURE | ANATOMIC RELATIONSHIP TO VEIN | ERROR IN PROCEDURE | INJURY |
|---|---|---|---|
| **Subclavian Vein Cannulation** | | | |
| Subclavian artery | Posterior and slightly superior, separated by the scalenus anterior—10-15 mm in adults, 5-8 mm in children | Insertion too deep or lateral | Hemorrhage, hematoma, possible hemothorax |
| Brachial plexus | Posterior to and separated from the subclavian vein by the scalenus anterior and the subclavian artery (20 mm) | Same as with the subclavian artery | Possible motor or sensory deficits in the hand, arm, or shoulder |
| Parietal pleura | Contact with the posteroinferior side of the subclavian vein, medial to the attachment of the anterior scalenus muscle to the first rib | Needle penetrates beneath or through both walls of the subclavian vein | Pneumothorax |
| Phrenic nerve | Same as with the parietal pleura | Placement of the needle above or behind the vein or penetration of both its walls | Paralysis of the ipsilateral hemidiaphragm |
| Thoracic duct | Crosses the scalenus anterior and enters the superior margin of the subclavian vein near the internal jugular junction | Same as with the phrenic nerve | Soft tissue lymphedema or chylothorax on the left |
| **Internal Jugular Vein Cannulation** | | | |
| Carotid artery | Passes with the jugular vein in the carotid sheath, consistently medial and deep to the vein | Insertion site too medial or the course of the needle not directed at the ipsilateral nipple | Hematoma, possible cerebral thromboembolism or airway obstruction |
| Phrenic nerve | Passes along the anterior surface of the scalenus anterior, behind the vein | Insertion too deep | Paralysis of the ipsilateral hemidiaphragm |
| Brachial plexus | Separated from the internal jugular by the scalenus anterior | Insertion too deep or too lateral | Possible motor or sensory deficits in the hand, arm, or shoulder |
| **Femoral Vein Cannulation** | | | |
| Femoral artery | Lies lateral to the vein in the femoral triangle | Needle passed too laterally | Hematoma |
| Psoas muscle | Directly posterior to the artery and vein | Needle passed too deep | Hematoma, psoas abscess |
| Bowel | Proximal and deep to the femoral vein | Needle passed too deep and above the inguinal ligament | Enterotomy, peritonitis |
| Synovial capsule of the hip | Deep to the psoas muscle | Needle passed too deep, particularly in small children | Arthritis, septic joint |

From Knopp R, Dailey RH. Central venous cannulation and pressure monitoring. *JACEP.* 1977;6:358.

review of all central catheters placed in the ED (supraclavicular SV, IJ, and femoral lines) reported a mechanical complication rate of 3.4%, or 22 of 643 lines placed.[124] Complications were defined as pneumothorax, hematoma, line misplacement, hemothorax, or any issue with the CVC (excluding infection or thrombosis) that required an inpatient consultation. In general, failure and complication rates increase as the number of percutaneous punctures increase. Historically, operator skill and experience have reliably predicted complication or success rates.[42,73] It has previously been reported that clinicians who have placed more than 50 CVCs have less than half the complication rates of those who have fewer than 50 attempts.[73]

Published complication rates vary in the literature and can now be classified according to whether ultrasound guidance was used during the procedure (Table 22-5).[42,47] Recent studies have demonstrated that ultrasound-guided CVC placement techniques have improved success rates, reduced complication rates, and decreased time needed to perform the procedure.[46-49] As a result, ultrasound guidance for CVC placement is recommended by the U.S. Department of Health and Human Services. Reports by the AHRQ list ultrasound guidance for central vein cannulation as one of its most highly rated safety practices.[57,125]

## Mechanical Complications

The most commonly reported mechanical complications are arterial puncture, hematoma, and pneumothorax. Inadvertent arterial puncture and hematoma formation are usually easily recognized and controlled with simple compression. Rarely, an artery is lacerated to such an extent that bleeding is significant and operative repair is necessary. In cardiac arrest, low-flow, or shock states, arterial puncture may not be obvious, and arterial cannulation and intraarterial administration of medications have occurred. This can lead to the subsequent development of ischemia or thrombosis of the artery and limb. When systolic blood pressure rises, arterial pulsations become more obvious. In critically ill patients, however, this complication may escape detection for some time. It has been reported that ultrasound-guided placement of IJ CVCs decreases the rate of arterial puncture to 1.4%.[47]

Though poorly studied, patients with a coagulopathy may experience significant bleeding from CVC placement, especially if arterial puncture or laceration has occurred. Mumtaz and coworkers cited a 3% bleeding rate in coagulopathic patients who experienced only minor bleeding that could be controlled with digital pressure.[44] Although central venous access may be performed safely in patients with underlying disorders in hemostasis without correction of the coagulopathy, caution is nevertheless urged. Areas amenable to arterial compression are preferred in these patients.[44]

Pneumothorax occurs in up to 6% of subclavian venipunctures and can also occur with the IJ approach[42,73,126] (Fig. 22-22A). Initially, the importance of this complication was minimized, but reports of fatalities caused by tension pneumothorax, bilateral pneumothorax, and combined hemopneumothorax followed.[55] One would expect a higher incidence of pneumothorax if the procedure is performed during CPR or positive pressure ventilation. A small pneumothorax can quickly become a life-threatening tension pneumothorax with positive pressure ventilation. Treatment of a catheter-induced pneumothorax is controversial, but not all patients will require formal tube thoracostomy. Some authors have reported that many stable outpatients exhibiting a pneumothorax after insertion of a CVC can be managed successfully by observation alone (60% in one series) or catheter (pigtail/Heimlich valve) aspiration, with large tube thoracostomy being reserved for refractory cases or emergency settings.[126,127] Critically ill patients or those undergoing mechanical ventilation are more likely to require invasive treatment of a catheter-induced pneumothorax.

Hemothorax may occur after laceration of the SV or subclavian artery, puncture of the pulmonary artery, or intrathoracic infusion of blood (Fig. 22-22B). Hydrothorax occurs as a result of infusion of IV fluid into the pleural space. Hydromediastinum is also possible. These are rarely serious complications, but fatalities have been reported. Surgical repair is occasionally required. Arteriovenous fistula formation has also been reported.[128] Additional pulmonary complications include tracheal and endotracheal cuff perforation.

Air embolism is a very rare, but potentially life-threatening complication of central venous cannulation. Undoubtedly, minor and clinically inconsequential amounts of air enter the

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**TABLE 22-5** Frequency of Complications without and with Ultrasound Guidance

| COMPLICATION | WITHOUT ULTRASOUND | | | WITH ULTRASOUND |
| --- | --- | --- | --- | --- |
| | IJ | SV | Femoral | IJ |
| Arterial puncture | 6.3-9.4% | 3.1-4.9% | 9.0-15.0% | 1.8% |
| Hematoma | <0.1-2.2% | 1.2-2.1% | 3.8-4.4% | 0.4% |
| Hemothorax | 0% | 0.4-0.6% | NA | 0% |
| Pneumothorax | <0.1-0.2% | 1.5-3.1% | NA | 0% |
| Infection (rate per 1000 catheter-days) | 8.6 | 4 | 15.3 | NA |
| Thrombosis (rate per 1000 catheter-days) | 1.2-3 | 0-13 | 8-34 | NA |

Data from References 47, 78, 129.
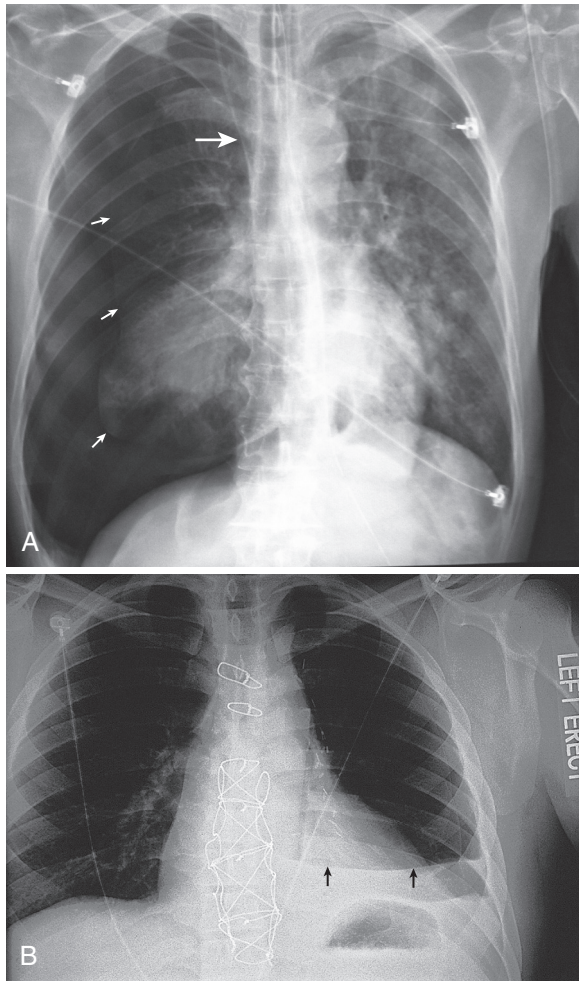*IJ,* internal jugular; *NA,* not applicable; *SC,* subclavian vein.

**Figure 22-22** Pneumothorax and hemothorax. A chest radiograph should be taken routinely to assess the position of a central venous catheter introduced via the subclavian or internal jugular route. This confirms placement of the catheter. Chest radiography can also show potential complications of the procedure. **A,** Large right pneumothorax after right internal jugular catheterization. The catheter is still in place (*large arrow*), and the absence of lung markings on the right and the pleural reflection (*small arrows*) are readily apparent. **B,** Left hydropneumothorax after left subclavian venipuncture (the catheter was removed before this radiograph). Note the straight line of fluid (air-fluid level) and no meniscus, a finding indicating that a *pneumothorax must also be present*. The edge of the partially collapsed lung is difficult to appreciate. No clinician can place central venous catheters and fail to have at least some complications that are inherent to the procedure, regardless of even flawless technique.

venous circulation during many cannulation procedures. Maintaining constant occlusion (with the operator's finger) on all needles that are located in central veins can minimize this occurrence. A 14-gauge needle can transmit 100 mL of air per second with a 5–cm $H_2O$ pressure difference across the needle.[95] Air embolism may occur if the line is open to air during catheterization or if it subsequently becomes disconnected. The recommended treatment is to place the patient in the left lateral decubitus position to relieve air bubble occlusion of the right ventricular outflow tract.[95] If this is unsuccessful, aspiration with the catheter advanced into the right ventricle has been advocated.[95] Emergency thoracotomy

to aspirate air (see Chapter 18) and cardiothoracic surgical consultation may also be warranted.

Catheter or wire embolization resulting from shearing of a through-the-needle catheter by the tip of the needle is a serious and generally avoidable complication. Embolization can occur when the catheter or wire is withdrawn through the needle or if the guard is not properly secured. Adverse events after embolization include arrhythmias, venous thrombosis, endocarditis, myocardial perforation, and pulmonary embolism.[75] The mortality rate in patients who did not have these catheters removed has been reported to be as high as 60%.[75] Transvenous retrieval techniques by interventional radiology are usually attempted, followed by open surgery if they are unsuccessful.[75] Entire guidewires may also embolize to the general circulation if the tip is not constantly secured by the operator throughout the procedure. Although the precise incidence of retained or "lost" guidewires is unknown, it is rarely reported in the literature. Initiatives by national safety bodies such as the National Quality Forum in the United States have focused on reducing the incidence of retained wires by classifying them as "never" events that require mandatory reporting in many states.

Delayed perforation of the myocardium is a rare, but generally fatal complication of central venous catheterization by any route.[129] The presumed mechanism is prolonged contact of the rigid catheter with the beating myocardium. The catheter perforates the myocardial wall and causes tamponade either by bleeding from the involved chamber or by infusion of IV fluid into the pericardium. The right atrium is involved more commonly than the right ventricle.[95] All clinicians who insert such catheters or care for such patients should be aware of this deadly complication, which results in profound deterioration with hypotension, shortness of breath, and shock. Emergency echocardiography, pericardiocentesis, and operative intervention by a thoracic surgeon may all be required for salvage of the patient. This can also occur with misplacement of the CVC in the pericardiophrenic vein.[130,131] Fortunately, this complication is preventable by using a postinsertion chest film to confirm the position of the tip of the catheter and repositioning any catheter if the tip is within the cardiac silhouette.

Catheter knotting or kinking may occur if the catheter is forced or repositioned or if an excessively long catheter is used.[130-132] The most common result of kinking is poor flow of IV fluids, although rare complications as severe as SVC obstruction have been seen.[130-132]

Thoracic duct laceration is a frequently discussed complication of left-sided subclavian venipuncture; however, it is extremely uncommon and has been reported only as a complication of IJ, not SV cannulation.

Neurologic complications are extremely rare and presumably caused by direct trauma from the needle during venipuncture. Brachial plexus palsy and phrenic nerve injury with paralysis of the hemidiaphragm have been reported.[133,134] Infusing hypertonic medications into the IJ vein via a malpositioned catheter may result in a variety of neurologic complications from retrograde perfusion of intracranial vessels.[135]

## Infectious Complications

Infectious complications include local cellulitis, thrombophlebitis, generalized septicemia, osteomyelitis, and septic

arthritis.[54] The incidence of septic complications varies from 0% to 25%.[70,136] The frequency with which infectious complications occur is directly related to the attention given to aseptic technique during insertion and aftercare of the catheter. Femoral venous catheterization carries a greater risk for infection than subclavian catheterization does. Merrer and associates reported the overall infectious complication rate from femoral and subclavian catheters to be 19.8% and 4.5%, respectively.[129] Ultrasound-guided IJ CVC placement has resulted in a decrease in the rates of central line–associated bloodstream infections (CLABSIs).[49] The exact mechanism by which ultrasound-guided CVC placement results in a lower risk for infection is unclear; it may be related to a reduced number of skin punctures. Organisms most commonly recovered from colonized femoral catheters are coagulase-negative staphylococci, Enterobacteriaceae, *Enterococcus* species, and *Pseudomonas aeruginosa*.[129]

CVCs cause an estimated 80,000 CLABSIs and are implicated in up to 28,000 deaths per year in patients in the intensive care unit.[60-62] The average cost has been estimated at $45,000 per patient with a CLABSI, with an cumulative cost of $2.3 billion annually.[60-62] Recently, the Centers for Disease Control and Prevention has recommended that central line bundling policies be implemented to significantly decrease the incidence of CLABSI.[61,62] This bundling policy includes five evidence-based interventions: (1) hand washing, (2) maximal barrier precautions, (3) chlorhexidine skin antisepsis, (4) optimal catheter site selection with avoidance of the femoral vein if possible, and (5) daily review of the necessity for the line and prompt removal of unnecessary lines.[63]

## Thrombotic Complications

Thrombosis and thrombophlebitis are significant risks associate with placement of a CVC. The risk for catheter-related thrombosis is directly related to the site of access. In one trial, catheter-related thrombosis was reported in up to 21.5% of patients with femoral CVCs and in 1.9% of patients with SV CVCs. For SV and IJ CVCs, it is important to determine that the tip of the catheter rests in the SVC, especially during the infusion of irritating or hypertonic solutions.[129] Thrombi may form secondary to prolonged contact of the catheter against the vascular endothelium. One autopsy study found a 29% incidence of mural thrombi in the innominate vein, SVC, and right ventricle of patients who had central lines in place an average of 8 days before death.[65] The clinical importance of these thrombi remains unclear; however, any thrombosis has the potential to embolize. Moreover, catheter-related thrombosis is a cause of SVC obstruction syndrome.[137]

## Subclavian Approaches

Although both approaches to the SV are relatively safe, the infraclavicular SV approach is more likely to be associated with complications. In a randomized, prospective comparison of supraclavicular SV and infraclavicular SV puncture in 500 ED patients, complication rates were 2.0% and 5.1%, respectively.[138] The most significant complications are pneumothorax and puncture of the subclavian artery; the highest reported incidence of pneumothorax is 2.4%.[18,66,138] Adherence to the techniques recommended for supraclavicular SV puncture decreases the risk for these complications because the needle is directed away from the pleural dome and subclavian artery. The relatively superficial location of the vein when approached from above the clavicle (1.5 to 3.5 cm) lessens the risk for puncture or laceration of deep structures.

## IJ Approach

Many complications of IJ cannulation are similar to those of SV access. The incidence of complications appears to be higher with use of the left IJ vein than with the right.[16] One common complication unique to the IJ approach is a localized hematoma in the neck.[139] With the IJ approach, pressure can easily be maintained on the area of swelling, and most hematomas will resolve spontaneously. If puncture of the carotid artery is recognized and treated with compression, it rarely causes significant morbidity in the absence of marked atherosclerotic disease, although arteriovenous fistulas may occur after IJ puncture.[128] Several neurologic complications unique to the IJ site of venipuncture have also been reported as a result of hematomas or direct injury. Such complications include damage to the phrenic nerves, iatrogenic Horner's syndrome, trauma to the brachial plexus, and even passage of a catheter into the thecal space of the spinal canal.[135] If the carotid artery is punctured, one may again attempt IJ or SV cannulation on the same side after appropriate, prolonged (15- to 20-minute) compression. The IJ vein valve is frequently damaged when cannulated, which often results in incompetence of the valve. The clinical significance of this, if any, is unknown.[140]

## Femoral Approach

Because vital structures in the neck and chest are not at risk, complications of femoral vein cannulation are generally less severe than those of other routes for central venous access. The most common immediate complications involve bleeding from damage to either the femoral artery or the femoral vein (Fig. 22-23). This can usually be managed with 10 to 15 minutes of direct pressure. Extra care should be taken in anticoagulated patients or after the administration of thrombolytic agents. In extreme cases when hemostasis cannot be achieved through direct pressure, a vascular surgeon should be consulted.

The peritoneum can also be violated with resultant perforation of the bowel. Bowel penetration is especially likely if the patient has a femoral hernia. Injury to the bowel is usually minimal and unlikely to require specific treatment. Nonetheless, the potential bacterial contamination of the femoral puncture site can pose a significant problem. Aspiration of air during placement of a femoral line necessitates removal of the catheter and reinsertion at another site. Other complications include muscular abscesses, infection of the hip joint, damage to the femoral nerve, and puncture of the bladder. Risk for these outcomes can be mitigated by strict aseptic technique, thorough assessment of landmarks, careful control of the needle's depth, and the use of bedside ultrasound.

Two more complications merit special mention. The first is the increased risk for catheter infection. Presumably caused by anatomic association with the anogenital region, many studies have found that femoral lines become infected at significantly higher rates than IJ or supraclavicular SV lines do.[61,62,65,129] Of note, some studies have failed to find a
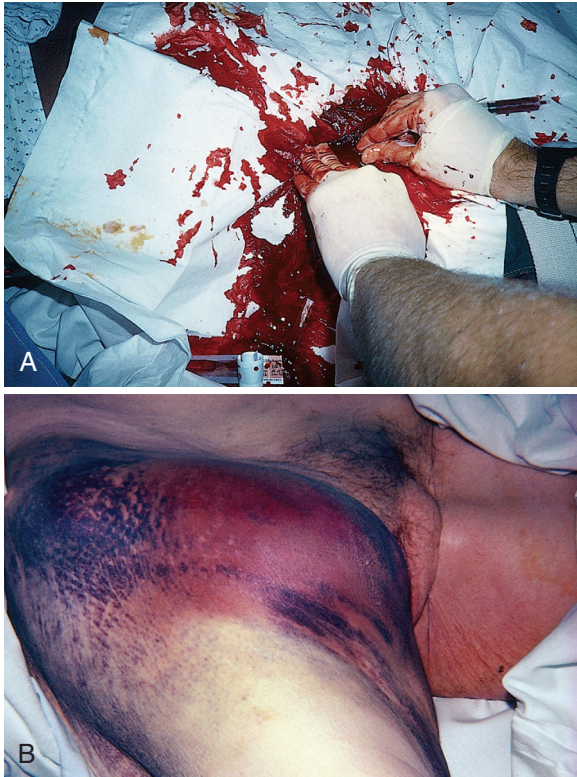
**Figure 22-23** A femoral vein catheter is more prone to deep vein thrombosis and infection than a subclavian or internal jugular line is, but it is a standard access route in the emergency department. Strict attention to sterile technique and limiting use to a few days will negate most of the negatives of this approach. **A,** Significant hemorrhage can occur after puncture of the femoral artery, but this area is readily compressed. The femoral route may be the approach of choice in a patient with an inadvertently placed arterial catheter who requires a central line. **B,** Bleeding from an inadvertently placed arterial catheter that was removed without adequate pressure in an anticoagulated patient.

statistical difference, and it is unclear how much of the effect is due to the actual location of the line versus how it is placed and managed.

The majority of studies show that the incidence of deep vein thrombosis is also increased in lines placed via the femoral route,[129,141] although the clinical significance of these clots has not been definitively addressed.

## TRAINING AND SIMULATION

CVC placement and ultrasound guidance techniques have a relatively steep learning curve. Simulation is recommended by the AHQR to teach these techniques.[57,125] Simulation training is independently associated with higher rates of correct needle insertion on the first attempt, as well as with higher successful CVC placement rates.[125,142,143] There are many simulation models that can be used. Kendall and Faragher described a phantom model as an easy, inexpensive method for ultrasound-guided CVC placement training.[144]

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