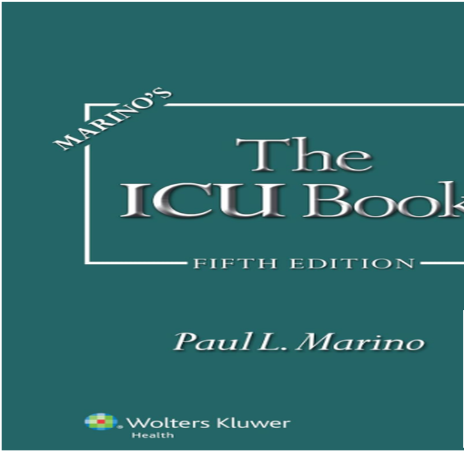
Marino's The ICU Book 5th Edition PDF



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Paul L. Marino

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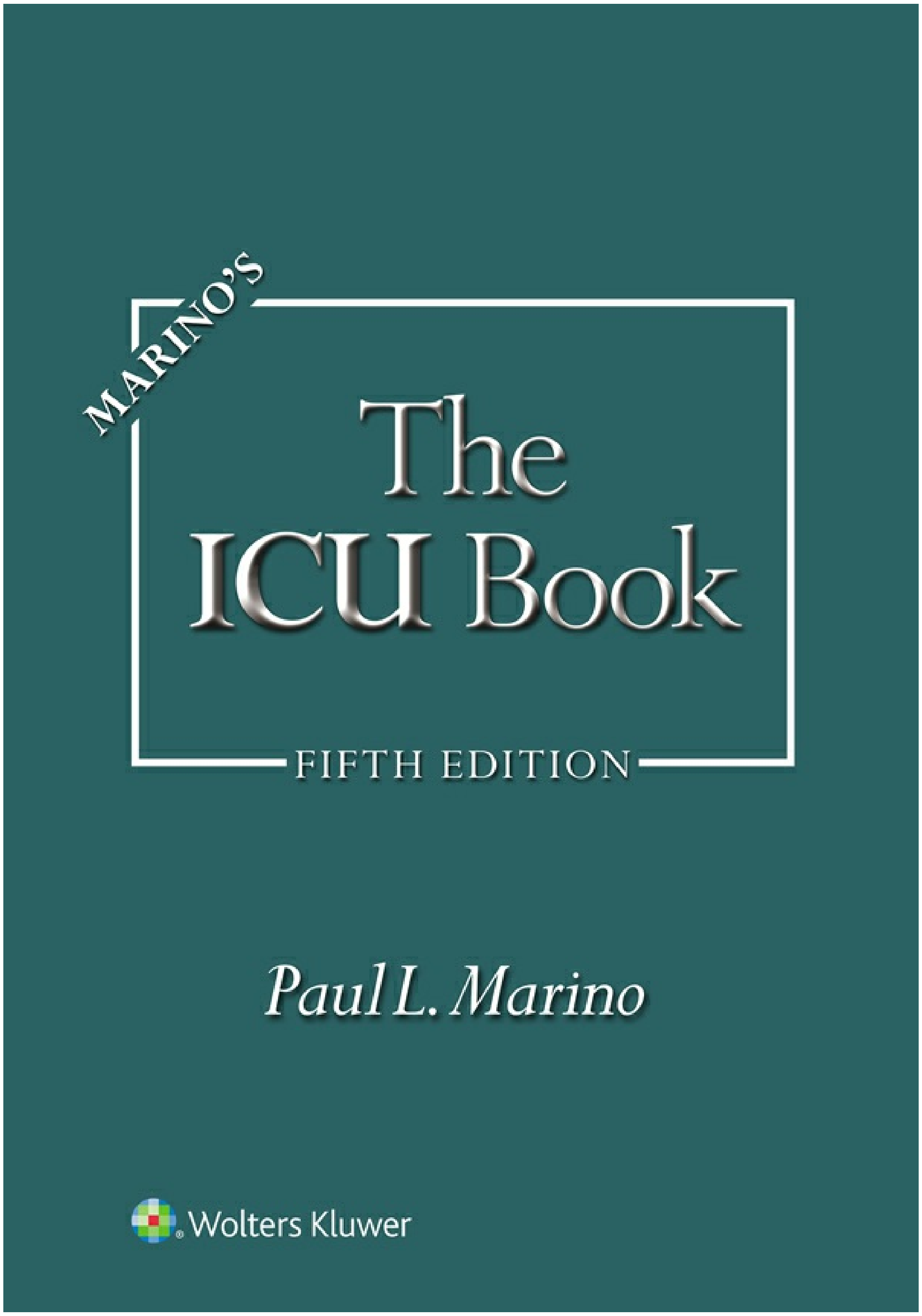

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Paul L. Marino, MD, PhD, FCCM
Clinical Associate Professor
Weill Cornell Medical College
New York, New York

Illustrations by Patricia Gast

Wolters Kluwer

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Acquisitions Editor: Keith Donnellan
Senior Development Editor: Ashley Fischer
Marketing Manager: Kirsten Watrud
Production Project Manager: Bridgett Dougherty
Manager, Graphic Arts & Design: Stephen Druding, Diane Drier
Manufacturing Coordinator: Lisa Bowling
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To my son,
Daniel Joseph Marino,
who is well into manhood,
but I can still see the little boy.

I would especially commend the physician who,
in acute diseases, by which the bulk of mankind
are cut off, conducts the treatment better than others.

HIPPOCRATES

Preface to Fifth Edition

The fifth edition of The ICU Book marks its 33rd year as a fundamental sourcebook for the care of critically ill adults. This edition continues the original intent to craft a textbook that focuses on fundamental concepts and practices that can be used in any ICU, regardless of the specialty designation of the unit. Creating succinct presentations that are easy to understand has always been a priority, and has been a popular feature of past editions.

This edition has been reorganized and completely rewritten, with updated references and clinical practice guidelines included at the end of each chapter. There are 53 chapters (two fewer than the fourth edition), with new chapters on Fluid Management (Chapter 11), Approaches to Clinical Shock (Chapter 14), Cardiogenic Shock (Chapter 16), Acute Pulmonary Embolism (Chapter 22), and Noninvasive Ventilation (Chapter 26). (Consolidation of the material in several chapters in the fourth edition has allowed for the addition of new chapters without increasing the total length of the book.) The text is supplemented with 238 original illustrations and 207 tables (an average of 4–5 illustrations and 4 tables per chapter) and each chapter ends with a brief section titled "A Final Word", where the author provides some insight about a relevant issue, or highlights some pertinent points in the chapter.

The ICU Book is unique in that it is the educational contribution of a single author, who has now accumulated 44 years of experience as a critical care specialist. The hope is that this contribution incites perceptions similar to those in the following quote (which is from the Foreword to another single-authored medical textbook) (1):

> "What a rarity! A single-authored medical text, regularly updated, the essence needed by newcomers and old-timers alike, extracted from the world's literature without assistance, barely increasing its bulk, while keeping it clear, concise, and comprehensive."

1. Severinghaus JW. Foreword. In: Nunn *JF. Nunn's Applied Respiratory Physiology*, 4th ed. Oxford: Butterworth-Heinemann Ltd, 1993.

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Acknowledgments are few but well deserved. First to Keith Donnellan, my editor and my friend, whose affable nature is matched only by the mastery of his craft. And to Patricia Gast, my longtime associate and ‘right arm’, who is responsible for the illustrations, tables, and page layouts in this book. This is our 6th book together, and none of them would have been possible without her. And finally, to the online library service of Weill Cornell Medical College, which provides ready access to innumerable English-language medical journals (a must for any author of a medical text).

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Section I

VASCULAR ACCESS

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

Louis Nizer
Between You and Me
1948

Chapter 1

Vascular Access Primer

It is not a bad definition of man to describe him as a tool-making animal.

Charles Babbage ([a])

INTRODUCTION

One of the most dramatic events in medical self-experimentation took place in a small German hospital during the summer of 1929, when an intrepid surgical resident named Werner Forssmann inserted a plastic urethral catheter into the basilic vein in his right arm and advanced the catheter into the right atrium of his heart (1). This was the first documented instance of a right-heart catheterization in a human subject, but Dr. Forssmann received no accolades, as he had acted in defiance of the senior surgical staff at his hospital. Instead, he was promptly dismissed from his residency for actions that were perceived as inappropriate and reckless. Upon dismissal, he was told that "such methods are good for a circus, but not for a respected hospital" (1). Dr. Forssmann went on to become a country doctor, but his achievement in vascular cannulation was finally recognized in 1956, when he was awarded the Nobel Prize in Medicine.

Werner Forssmann's achievement was possible because he used a flexible plastic catheter that could safely follow the contours of the venous system as it was advanced. This was a departure from the traditional practice of cannulating blood vessels with rigid needles and metal cannulas, and it heralded the modern era of vascular cannulation, which employs a wide array of flexible plastic catheters like the ones described in this chapter.

CATHETER BASICS

Vascular catheters are made of synthetic plastic polymers that are chemically inert, biocompatible, and resistant to chemical and thermal degradation. Catheters that are used for short-term cannulation (days to weeks) are typically made of *polyurethane*, a versatile polymer that is pliable, yet provides enough tensile strength to resist kinking during catheter insertion. (The elastic fibers used in stretchable clothing are made of polyurethane.) Catheters that are used for long-term vascular access (months) are typically made of *silicone*, which is much more pliable than polyurethane (e.g., the nipple on baby bottles is made of silicone) and is less likely to cause vascular damage. Because of their pliability, silicone catheters are difficult to insert percutaneously, and are used primarily as implantable catheters (such as those used for long-term chemotherapy).

Catheter Size

The size of vascular catheters is a reflection of the *outside diameter* of the catheter. There are two expressions of catheter size: gauge size and French size. The correlation between the two is shown in Table 1.1.

Gauge Size

The gauge system was introduced (in England) for sizing solid iron wires, and was later adopted for hollow needles and catheters. Gauge size is a measure of how many wires (or catheters) can be placed side-by-side in a given space, and it varies inversely with outside diameter (OD); i.e., the higher the gauge size, the more catheters will fit in a given space, and thus the smaller the OD. Unfortunately, the actual OD for each gauge size is not standardized, and varies with each manufacturer. Gauge sizes are typically used for needles, small-bore single-lumen catheters, and the infusion channels in multilumen catheters; sizes typically range from 16 gauge (largest diameter) to 21 gauge (smallest diameter).

French Size

The French system was introduced (guess where) for sizing hollow tubes (catheters), and it provides a more predictable measure than the gauge system. The French scale begins at zero, and each increment of one French unit represents an increase in OD of 0.33 millimeters (2): i.e.,

$$\text{French size (Fr)} \times 0.33 = \text{OD (mm)}. \tag{1.1}$$

French sizes are used for multilumen catheters and large-bore single-lumen catheters; sizes typically range from 4 Fr (1.2 mm OD) to 9 Fr (3.2 mm OD). French sizing is also used for urinary catheters, nasogastric tubes, and pleural drainage tubes.

Flow Through Catheters

The determinants of flow through narrow, rigid tubes (e.g., catheters) was first described by a German civil engineer (Gotthilf Hagen) and a French physician (Jean Marie Poiseuille), working independently in the mid-19th century. Their observations are expressed in the following equation, known as the *Hagen-Poiseuille equation* (3).

$$Q = \Delta P \times (\pi r^4/8\mu L). \tag{1.2}$$

This equation states that the steady or laminar flow rate (Q) in a rigid tube is directly related to the pressure gradient along the tube ($\Delta P = Pin - Pout$) and the fourth power of the radius of the tube (r^4), and is inversely related to the length of the tube (L) and the viscosity of the fluid (μ). The term enclosed in parentheses is equivalent to the reciprocal of resistance (according to the relationship: $Q = \Delta P \times 1/R$), so the resistance to flow can be expressed as: $R = 8\mu L/\pi r^4$.

TABLE 1.1 Correlation between French and Gauge Sizes

French Size	Gauge Size	Outside Diameter
1	27	0.4 mm
3	20	0.9 mm
4	18	1.2 mm
5	16	1.7 mm
7	13	2.4 mm
9	11	3.2 mm

From Access Technologies, 2016 catalogue (available at www.norfolkaccess.com).

Catheter Dimensions

The Hagen-Poiseuille equation describes the influence of catheter dimensions on flow through the catheter. This is an important consideration because *the infusion rate of intravenous fluids is determined by the dimensions of the indwelling catheter, and not by the size of the cannulated vein*. The inner radius of the catheter has a profound influence on flow (because flow rate is directly related to the fourth power of the radius), and this is demonstrated in the bar graph on the left in Figure 1.1 (4). In this case, the gravity-driven flow of water through a 16 gauge catheter was more than double the flow through an 18 gauge catheter, and was almost four times greater than the flow through a 20 gauge catheter (with all catheters being equal in length). The large difference in flow rates between 16 and 20 gauge catheters is associated with less than a one millimeter difference in outside diameter (see Table 1.1), which highlights the importance of catheter diameter as a determinant of flow.

The Hagen-Poiseuille equation also shows that flow will vary in an opposite direction to changes in the length of a catheter; this is demonstrated in the graph on the right in Figure 1.1 (5). Note that the transition from a two-inch catheter (a common length for peripheral vein catheters) to a six-inch catheter (a common length for central venous catheters) is associated with a 40% reduction in flow, and a further transition to a 12-inch catheter (an available length for central venous catheters) is associated with an additional 40% decline in flow.

The information just presented indicates that *when rapid volume infusion is needed, a large-bore catheter is the appropriate choice, and a short, large-bore catheter is the optimal choice.*

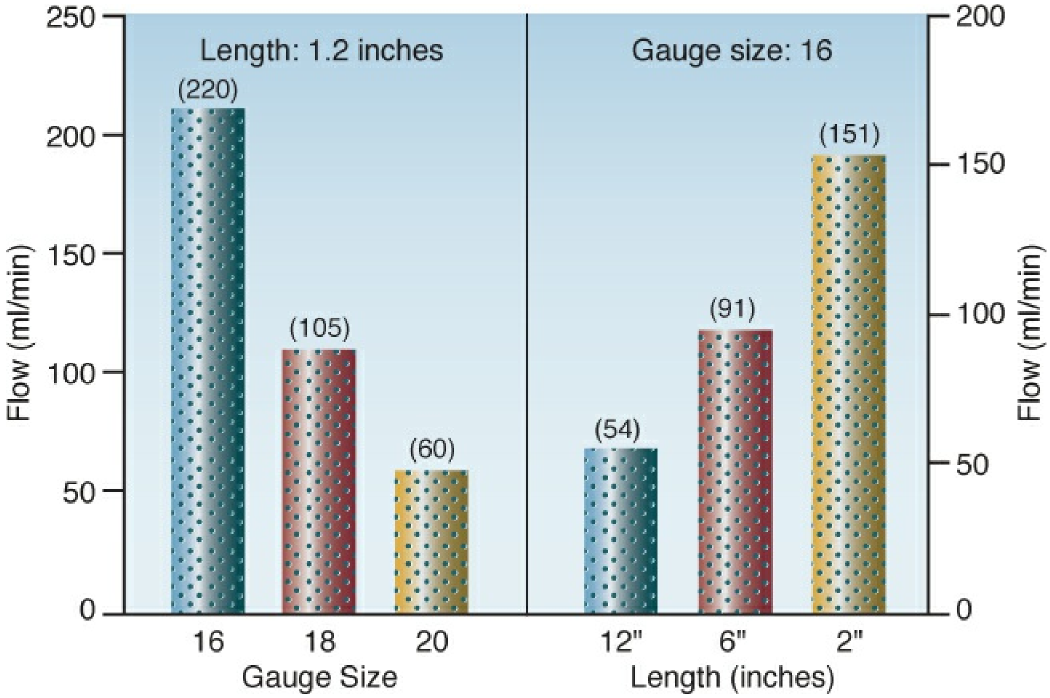

FIGURE 1.1 Graphs demonstrating the influence of catheter diameter (panel on the left) and catheter length (panel on the right) on flow rate. See text for further explanation. Data from References 4 and 5.

Infusion Pressure

The resistance to flow created by vascular catheters can be overcome by increasing the pressure gradient for flow (i.e., the ΔP in Equation 1.2). In a gravity-driven infusion system, this is accomplished by increasing the height of the infusate container (bag or bottle) above the cannulation site: e.g., a height of 68 cm (27 inches) will create an infusion pressure of 50 mm Hg (or one pound per square inch, psi), and an increase in height to 100 cm (39 inches) will increase the infusion pressure to 75 mm Hg (1.5 psi) (6).

INFUSION PUMPS: Intravenous fluids and drugs are typically delivered at specific infusion (or dose) rates, and this control is achieved with programmable infusion pumps that adjust the infusion pressure (up to 15 psi) to deliver a preselected infusion (or dosage) rate. There are two types of infusions pumps: *volumetric pumps*, which can deliver one liter of fluid (from a bag or bottle) at flow rates of 0.1 to 1,000 mL/hr, and *syringe drivers* that operate with a lower volume (up to 100 mL) and deliver fluid at rates of 0.1 to 100 mL/hr (6). *Volumetric pumps* are general-purpose devices that are used to deliver intravenous fluids and most intravenous drugs, while syringe pumps are popular for patient-controlled analgesia. There are also specialized infusion pumps for the resuscitation of massive hemorrhage. These devices deliver warmed fluids or blood products at rates of up to 1.5 L/min when combined with specialized "rapid infusion catheters" that are typically 7–8 French in diameter and 2–2.5 inches in length.

GENERAL-PURPOSE CATHETERS

Intravenous catheters are classified as central or peripheral catheters based on the following simple distinction: central catheters extend into one of the vena cavae, and peripheral catheters do not. The following is a description of the peripheral and central catheters that are used in everyday patient care in the ICU. Catheters with a specialized function, like hemodialysis catheters and pulmonary artery catheters, are described elsewhere in the book. (Chapter 8 is devoted entirely to the pulmonary artery catheter.)

Peripheral Catheters

Peripheral catheters are typically inserted into one of the veins in the upper extremity, and they do not extend beyond the shoulder. Three distinct types of peripheral catheter have been identified (7,8): short peripheral catheters (<6 cm in length), long peripheral catheters (6 to <15 cm in length), and midline catheters (15 to 20 cm in length).

Short Peripheral Catheters

The traditional method of cannulating peripheral veins involves a 16–22 gauge catheter that is 3–5 cm (1–2 in) in length, and is placed in a visible or palpable vein (usually in the upper extremity) using a catheter-over-needle device like the one in Figure 1.2. The tip of the catheter is recessed back from the tip of the introducer needle, and is tapered to prevent fraying as the catheter is advanced into the blood vessel. When the tip of the probe needle enters the vein, a “flashback” of blood appears in the clear hub of the needle. When this occurs, the catheter is advanced over the needle and into the lumen of the blood vessel.

Cannulation with short peripheral catheters is favored because it provides rapid vascular access (when a superficial vein is visible or palpable), although the initial cannulation attempt fails in about one-third of cases (9). The major disadvantage of short catheters is their limited “dwell time” (the time an indwelling catheter remains functional); the reported failure rate of these catheters is 40–60% within the first 3 days (8). Common causes of failure include localized phlebitis, catheter occlusion or dislodgement, and vascular perforation with extravasation of infused fluids. Short peripheral catheters are especially problematic in ICU patients, who are often agitated and prone to dislodging these catheters.

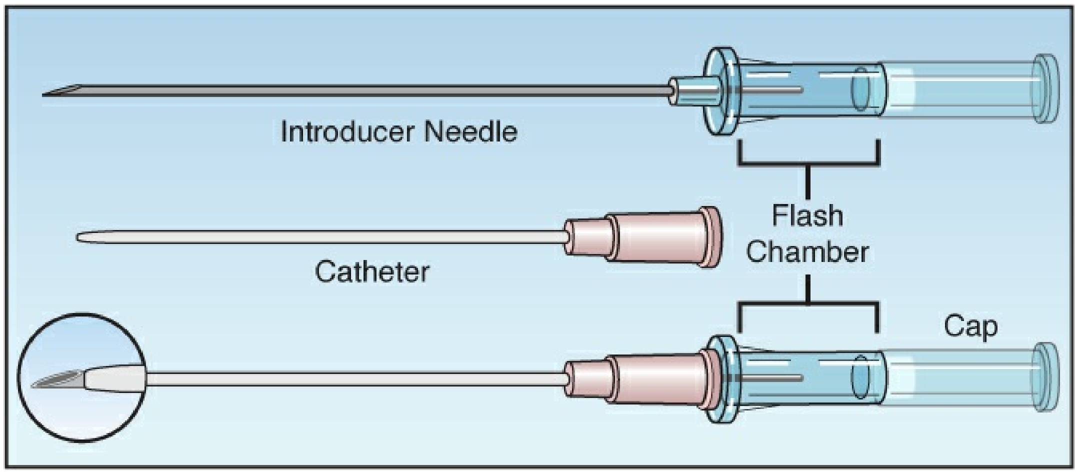

FIGURE 1.2 A catheter-over-needle device used to cannulate superficial peripheral veins.

Long Peripheral Catheters

Long peripheral catheters (also known as "extended dwell catheters") are typically 8 cm (3.1 inches) in length, and were introduced to improve the stability and dwell time of the short peripheral catheters. Clinical studies have consistently shown a longer dwell time with the longer catheters (about 7–9 days) (10). Despite this advantage, long peripheral catheters have not been embraced (at least not in North America), possibly due to the growing popularity of midline catheters (see next).

Midline Catheters

Midline catheters are the longest of the peripheral vein catheters (15–20 cm in length), and are inserted into one of three deep veins above the antecubital fossa: the basilic, brachial, or cephalic veins (see Figure 1.3). The basilic vein is preferred because it runs a direct course up the arm, and is not in close proximity to an artery or nerve (like the brachial vein). Because the major veins in the upper arm are deeply situated ultrasound guidance is used for midline catheter insertion (see later for a description of ultrasound guided cannulation). When properly placed and maintained, midline catheters can remain functional for weeks; e.g., in one clinical study, the average dwell time for midline catheters was 14 days (11). This same study also demonstrates that *vasopressors can be infused through midline catheters for as long as 7–8 days* without evidence of extravasation or limb compromise (11).

The extended dwell time of midline catheters have made them a popular choice when more than a few days of venous access is anticipated. In fact, midline catheters are now considered a safer alternative to the much longer "peripherally inserted central catheters" or PICCS (described in the next section), which have traditionally been favored for prolonged venous access. Comparative studies have shown that midline catheters have a lower incidence of catheter occlusions and catheter-related bloodstream infections than PICCs (12). Although there is a slightly higher risk of deep vein thrombosis (DVT) with midline catheters, the incidence of DVT with midline catheters is low (<5%), and the difference between midlines and PICCs is small (<2%) (13).

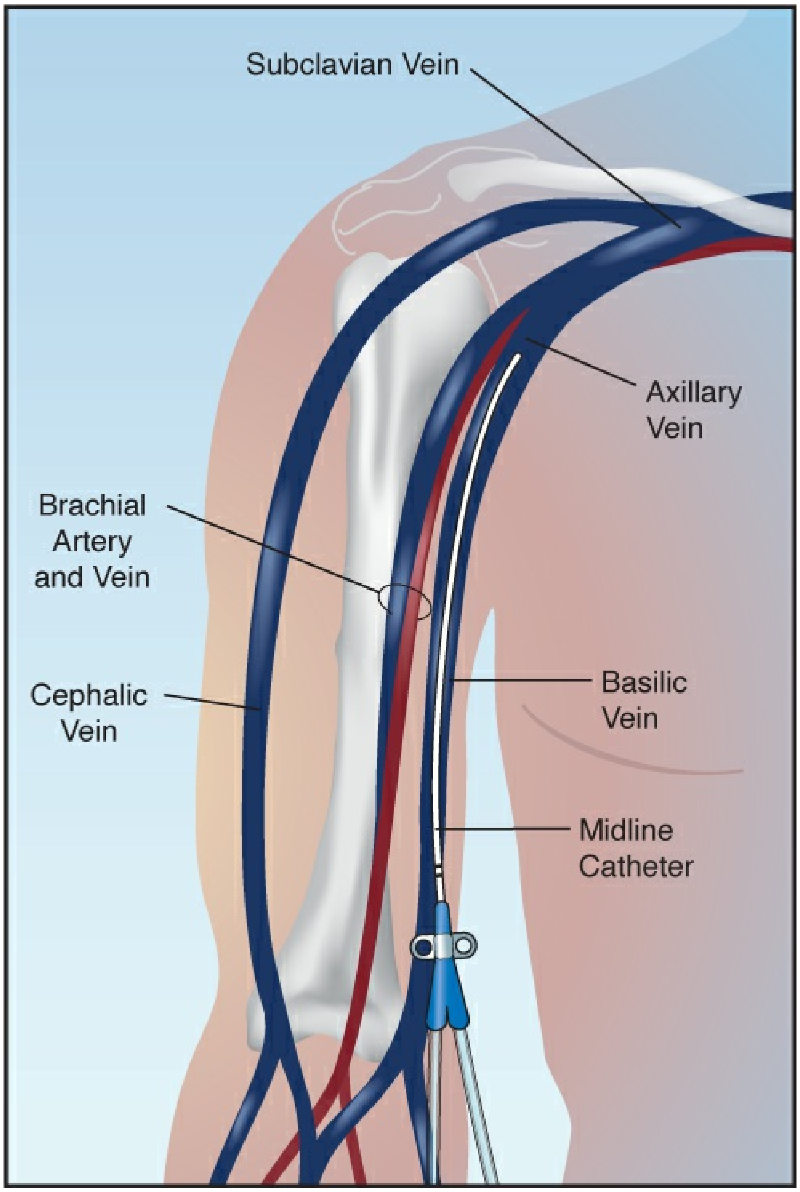

FIGURE 1.3 Illustration depicting the major veins un the upper arm, with a midline catheter in the basilic vein (the favored vein for midline catheter insertion).

TABLE 1.2 **Comparative Features of Selected Peripheral Catheters**

Catheter	Size	Length	Flow (L/hr)†
Short Peripheral Catheter[1]	18 ga	3 cm 1.2 in	6.0
Long Peripheral Catheter[2]	18 ga	8 cm 3.1 in	3.7
Double Lumen Midline Catheter[2]	Size: 5.5 French Lumens: 18 ga	15 cm 6 in	1.3/lumen

†All flow rates are for the gravity-driven flow of water from a height of 40 inches.

[1] Data from www.emupdates.com (accessed 5/17/2022).

[2] Data for Arrow® catheters, from www.teleflexvascular.com (accessed 5/17/ 2022). ga = gauge size, Fr = French

size.

Midline catheters are available in lengths of 15 cm and 20 cm, and can have one to three infusion channels. The double-lumen catheter that is 15 cm in length is a popular choice, and some features of this catheter are included in Table 1.2. Note that the increased length of the midline catheter is accompanied by a decrease in flow capacity; in this case, the gravity-driven flow rate in each lumen of the midline catheter is only about 20% of the flow rate in the short peripheral catheter. Despite this flow decrement, the gravity-driven flow capacity in the midline catheter still exceeds the maximum flow provided by volumetric infusion pumps (i.e., 1 L/hr).

Central Catheters

As mentioned earlier, central vein catheters have a tip in one of the vena cavae. There are two types of central catheters, based on the location of the insertion site: *peripherally inserted central catheters* (PICCs) are inserted into one of the veins in the upper arm, while *centrally inserted central catheters* (commonly known as *central venous catheters*) are inserted into one of the major veins near the thoracic inlet, or in the groin.

Peripherally Inserted Central Catheters

Peripherally inserted central catheters (PICCs) are essentially a longer version of the midline catheters: i.e., they are inserted via the same veins as the midline catheters, but are long enough to be advanced into the superior vena cava. These catheters have been popularized as a safer alternative to central venous catheters when peripheral vein cannulation is problematic, or when more than one week of vascular access is anticipated (14). However, the emergence of midline catheters as a safer alternative to PICCs has led to a steady decline in the popularity of PICCs in hospitalized patients.

PICCs are available in lengths ranging from 40 cm to 55 cm, and can have one to three infusion channels. A popular choice is the double-lumen PICC that is 50 cm in length, and some features of this catheter are shown in Table 1.3. Note that the extended length of the PICC results in a marked decrease in flow capacity: e.g., the PICC in Table 1.3 is more than three times the length of the midline catheter in Table 1.2, and the resulting flow capacity is only 20% of that in the midline catheter. The compromised flow capacity in PICCs may explain the relatively high incidence of occlusions in these catheters (12).

Central Venous Catheters

Central venous catheters (CVCs) have played a prominent role in providing both secure and multifunctional venous access in critically ill patients. (The insertion of CVCs is described in detail in the next chapter.) These catheters are available in lengths of 15 cm, 20 cm, and 30 cm, and can have as many as 4 infusion channels. The most popular CVC is a triple-lumen catheter like the one shown in Figure 1.4. Note that the distal lumen has a larger bore (16 gauge) than the proximal or medial lumens (18 gauge); as a result, the flow capacity in the distal lumen is more than double that in the other lumens, as indicated in Table 1.3. For this reason, the distal lumen of a CVC is best suited for rapid volume infusions.

TABLE 1.3 **Comparative Features of Selected Central Catheters**

Catheter	Size	Length	Lumens	Flow (L/hr)†
Triple Lumen CVC	7 Fr	20 cm (8 in)	Distal (16 ga) Medial (18 ga) Proximal (18 ga)	2.28 0.91 0.99
Double Lumen PICC	5.5 Fr	50 cm (20 in)	Distal (18 ga) Proximal (18 ga)	0.26 0.27

†All flows rates are for the gravity-driven flow of water from a height of 40 inches.

Data for Arrow® catheters, from teleflexvascular.com (accessed 5/18/2022).

CVC = central venous catheter,

PICC = peripherally inserted central catheter, ga = gauge size, Fr = French size.

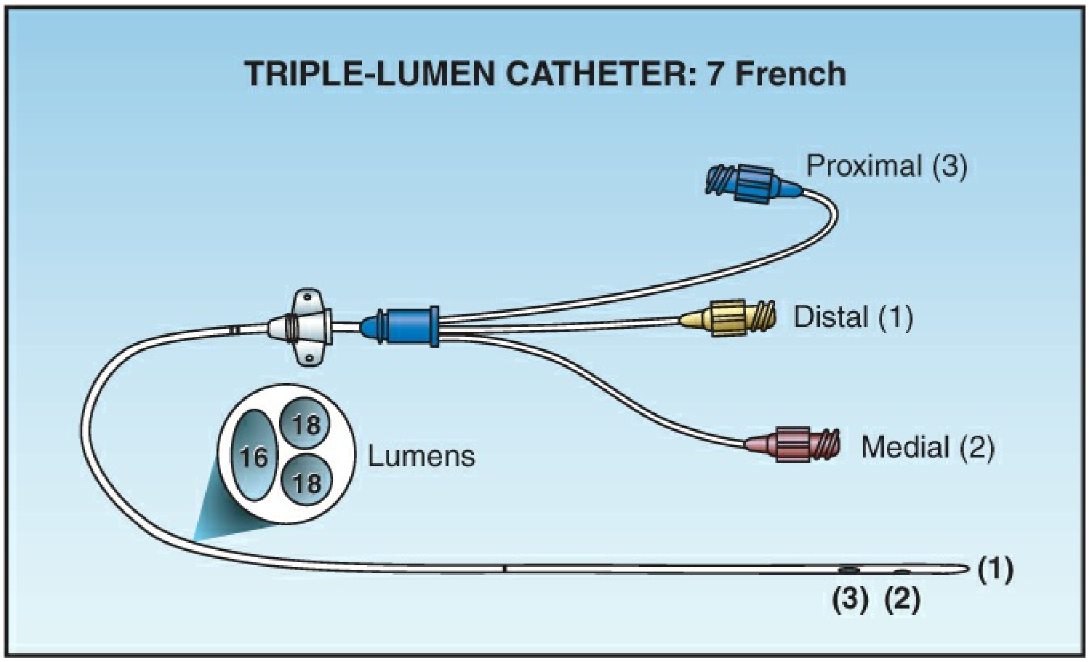

FIGURE 1.4 A triple-lumen central venous catheter, showing the gauge size of each lumen and the position of the outflow ports at the distal end of the catheter. This is currently the most popular design for central venous catheters.

The insertion of CVCs has been a staple of patient care in ICUs, but the popularity of CVCs is waning, as safer alternatives (i.e., PICCs and midline catheters) have emerged. (For more on the insertion of CVCs, see Chapter 2.)

The Guidewire

Cannulation of all but the most superficial, palpable veins is accomplished by advancing the catheter over a guidewire that is placed in the lumen of the vein. This technique of guidewire-assisted vascular cannulation, first introduced by a Swedish angiographer named Sven-Ibar Seldinger (and known as the *Seldinger technique*) (15), is illustrated in Figure 1.5. A small bore needle is used to probe for the target vessel. When the tip of the needle enters the vessel, a thin wire with a flexible tip is passed through the needle and into lumen of the blood vessel. (The flexible tip reduces the risk of en dothelial injury as the guidewire is advanced.) The needle is then withdrawn over the guidewire, and the catheter is advanced over the guidewire and into the lumen of the blood vessel. (In actual practice, a "dilator catheter" is first threaded over the guidewire to create a tract that facilitates catheter insertion.)

Summation

The advantages and disadvantages of general-purpose vascular catheters are summarized in Table 1.4. The following is a brief summary of how these catheters are used for patient care in the ICU. Short peripheral catheters are preferred for quick intravenous (IV) access at the outset, but in patients who spend more than a few days in the ICU, more stable IV access is needed. This has been traditionally supplied by CVCs, but over the past decades, PICCs began to replace CVCs for longer-term IV access. More recently, midline catheters have emerged as an acceptable choice for longer-term IV access, and they are replacing CVCs and PICCS for this purpose. However, PICCS continue to be popular for patients who require extended (several weeks) IV therapy. The major drawback of midline catheters and PICCs is the use of specially trained teams to insert the catheters; this limits the availability of these catheters.

Central venous catheters are the final (go-to) catheters for stable venous access, and are especially preferred in patients with life-threatening hemodynamic instability.

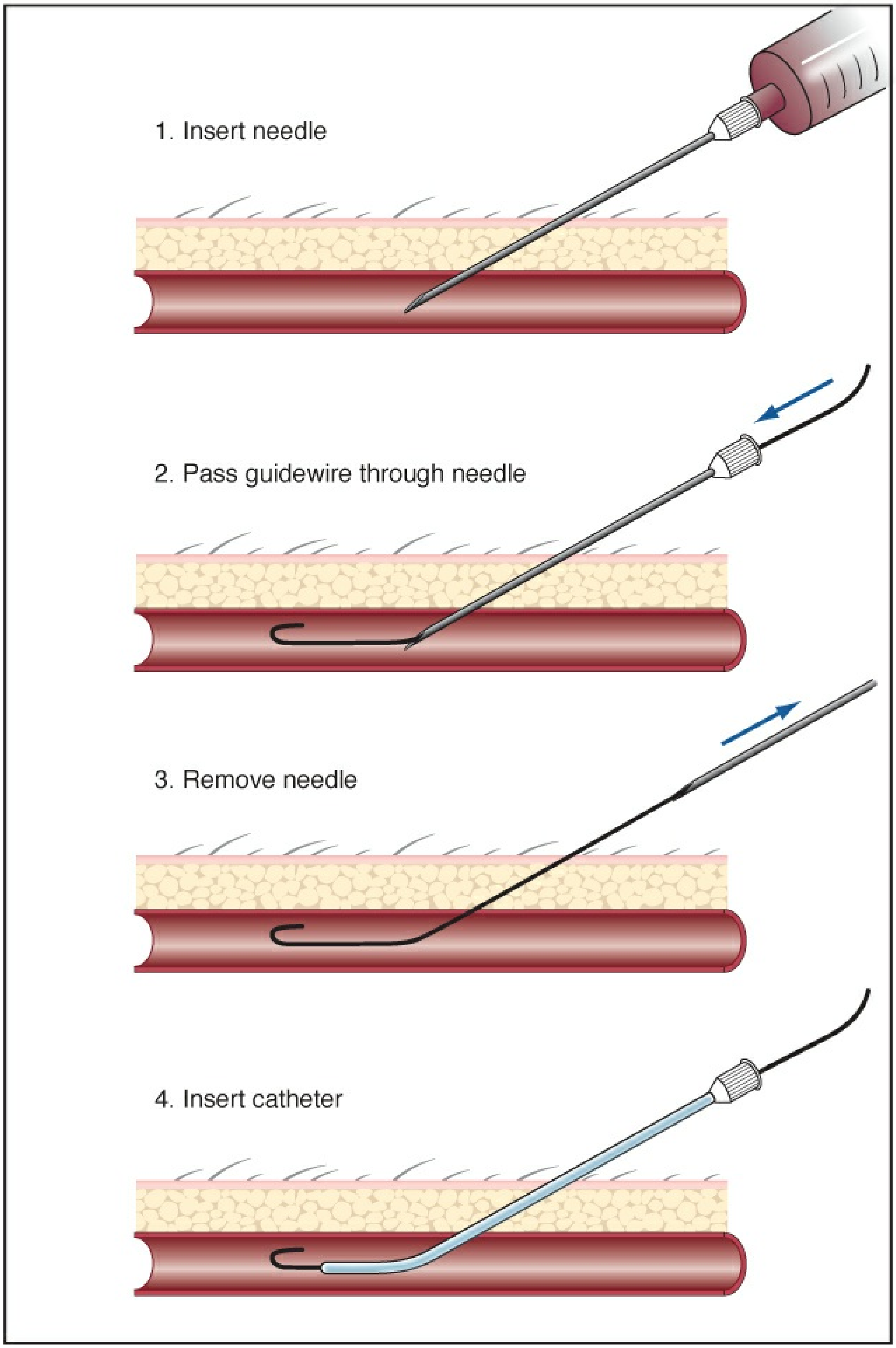

FIGURE 1.5 The steps involved in guidewire-assisted cannulation of blood vessels (the Seldinger technique).

TABLE 1.4 **Summary of the General-Purpose Venous Catheters**

Type of Catheter	Advantages	Disadvantages
Peripheral Catheters		
Short Catheter	Rapid IV access Low risk of septicemia	Limited dwell time High failure rate
Long Catheter	Longer dwell time than short catheters	Can require ultrasound-guided insertion
Midline Catheter	Longest dwell time of peripheral catheters Multiple lumens Allows prolonged vasopressor infusions	Requires ultrasound-guided insertion and special training
Central Catheters		
Peripherally Inserted Catheter	Less risk, and greater patient acceptance, than central venous catheters	High occlusion rate Increased length can compromise infusion rate
Central Venous Catheter	Most versatile general-purpose catheter	Risk of serious complications

VASCULAR ULTRASOUND

The emergence of real-time ultrasound to guide vascular cannulation has added considerably to the success rate and safety of cannulating both central and peripheral veins (16,17). The following is a brief introduction to the methodology.

The Method

Vascular ultrasound uses linear array probes that emit high-frequency ultrasound waves (5–15 MHz); this produces high-resolution images, but limits the depth of tissue penetration (to about 9 cm). The waves that are reflected back to the probe (called *echoes*) are processed by a transducer that converts the ultrasound waves to gray scale images. Higher amplitude echoes produce brighter or whiter images, while lower amplitude echoes produce darker or blacker images. This methodology is known as B-mode (brightness-mode) ultrasound, and it produces two-dimensional, gray-scale images. Ultrasound waves pass readily through fluids, so blood vessels will have a dark gray or black interior on the ultrasound image.

Orientation of the Beam

The ultrasound beam can be aligned along the long axis of a blood vessel to produce a sagittal image of the vessel (long-axis view), or it can be oriented to transect a blood vessel, which produces a cross-sectional view of the vessel (short-axis view). This is demonstrated in Figure 1.6. Note that in the long-axis view, the probe needle advances along the plane of the ultrasound beam, and can be visualized along its entire path, while in the short-axis view, the probe needle does not meet the ultrasound beam until it reaches the target vessel, where it is visible only as a high-intensity dot on the ultrasound image.

Which View is Better?

Neither view is clearly superior to the other, and each has advantages and disadvantages. The advantage of the short axis view is greater ease in locating the target vein, and the ability to visualize both the vein and its affiliated artery (which reduces the risk of arterial puncture), while the disadvantage is the limited ability to view the probe needle. The long axis view allows visualization of the probe needle, guidewire, and catheter during the cannulation, but is unable to visualize an affiliated artery, and requires a vein that runs a relatively straight course.

At the present time, the short-axis view seems to be the preferred one for locating the target vessel and confirming puncture of the vessel with the probe needle. The long-axis view is preferred for confirming intraluminal placement of the guidewire and catheter (see next).

Protocol

The recommended protocol for ultrasound-guided vascular cannulation includes the following sequential steps (16): a) identify the target vein, b) verify puncture of the vein by the probe needle, and c) confirm intraluminal placement of the guidewire and catheter.

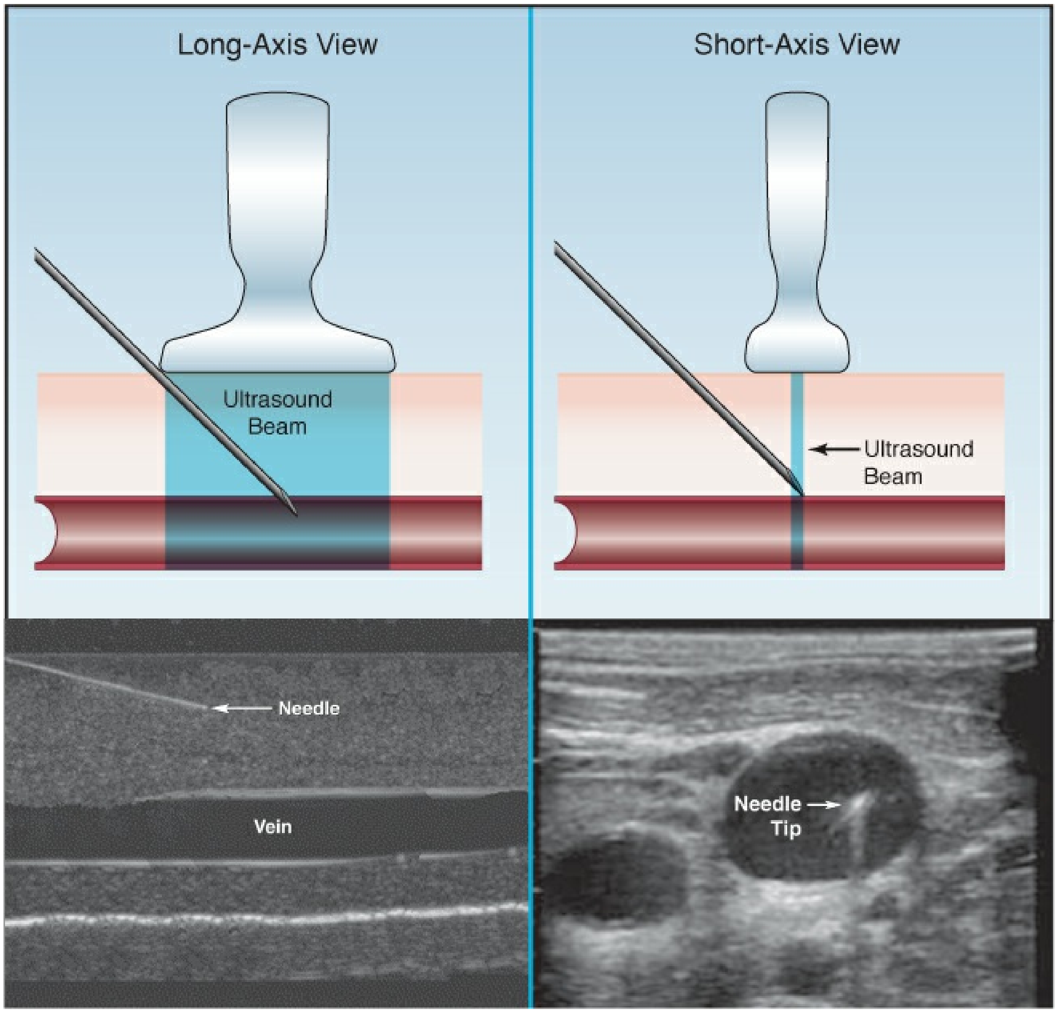

FIGURE 1.6 Orientation of the ultrasound beam in the long-axis and short-axis view, and how this influences the ability to visualize the probe needle. See text for further explanation.

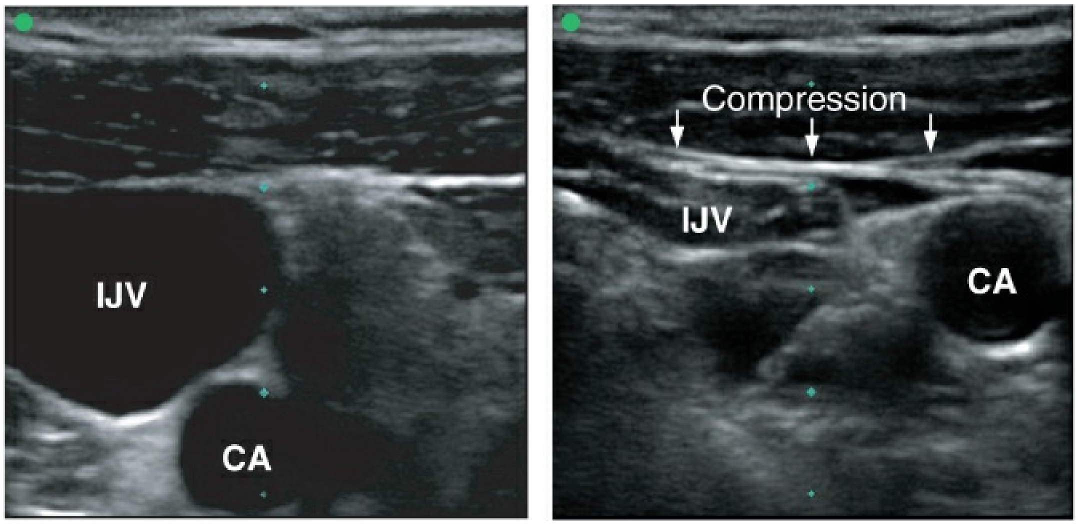

FIGURE 1.7 Compressibility for identifying veins. The image on the left is a short-axis view of the internal jugular vein (IJV) and carotid artery (CA) at the base of the neck, and the image on the right shows compression of the vein when downward pressure is applied to the overlying skin. The green dots mark the lateral side of each image.

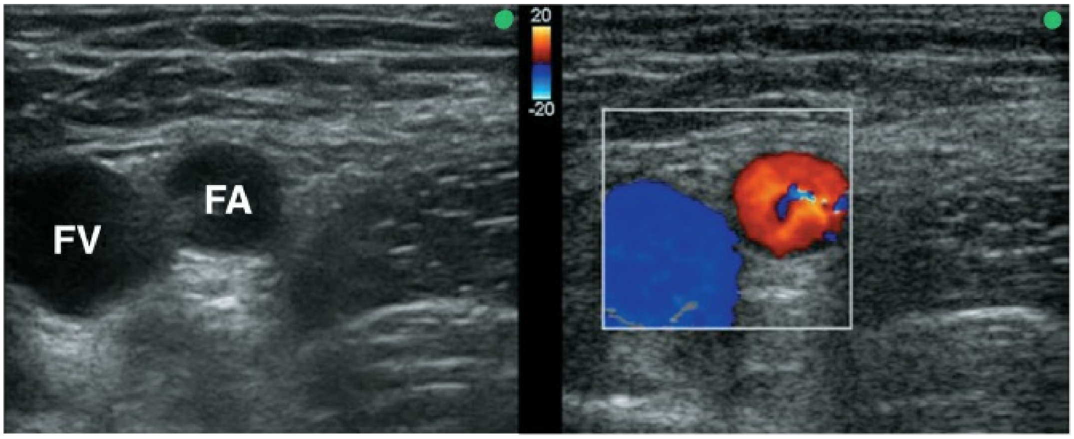

FIGURE 1.8 Color flow Doppler imaging for identifying arteries and veins. The image on the left is a short-axis view of the femoral artery (FA) and femoral vein (FV) in the groin, and the image on the right is a color Doppler image of the same blood vessels showing the artery in red and the vein in blue. The green dots mark the lateral side of each image.

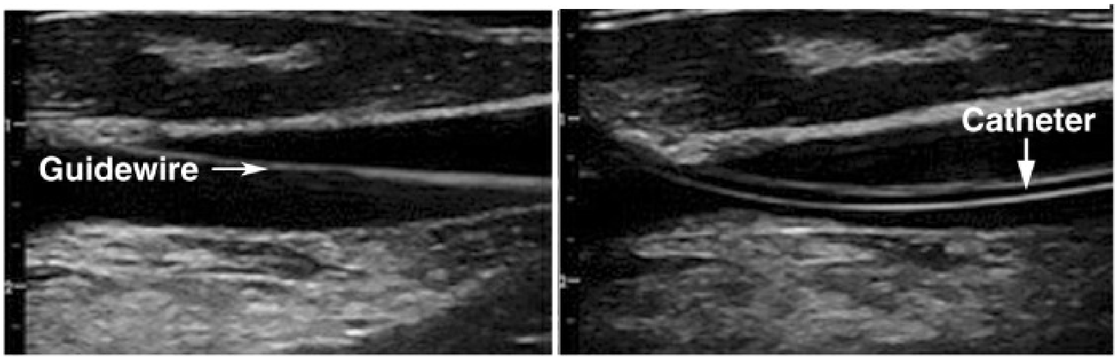

FIGURE 1.9 Long-axis view of the internal jugular vein showing intraluminal placement of the guidewire and catheter. Images from Reference 16.

Distinguishing Veins from Arteries

There are two methods for distinguishing arteries from veins using ultrasonography. The easiest (and most popular) method is to determine the compressibility of the blood vessel; i.e., when pressure is applied to the skin overlying a blood vessel, a vein will collapse much more readily than an artery. This is demonstrated in Figure 1.7, which shows an internal jugular vein that is compressed by pressing down on the overlying skin, while the nearby carotid artery is unaffected. (*Note:* One exception to this behavior is the presence of venous thrombosis, because a vein that is filled with a thrombus will not be compressible).

The other method for identifying arteries and veins is color Doppler imaging, where the frequency shift produced by the direction of blood flow (the Doppler effect) is converted into color images, and superimposed on the gray-scale ultrasound image (18). An example of this is shown in Figure 1.8, with the red color marking the femoral artery and the blue color marking the femoral vein. These colors are not specific for arteries and veins, but instead represent the direction of blood flow in relation to the ultrasound probe. (The color assignments are indicated on the color legend in Fig. 1.8.)

The Probe Needle

Advancing the probe needle to puncture the target vein is easily visualized in the long-axis view, as shown in Figure 1.6. In the short-axis view, the probe needle is advanced using short, stabbing thrusts to produce tissue displacement, which marks the path of the needle, and puncture of the target vein is verified by observing a high-intensity dot in the lumen of the vessel, as shown in Figure 1.6.

Confirming Catheter Placement

Veins tend to collapse when punctured, creating a tendency for probe needles to puncture the posterior wall of the vein. In one study, posterior wall perforation occurred in 40% of ultrasound-guided cannulations using the short-axis view, and 18% of cannulations using the long-axis view (19). Because of this risk (and the popularity of the short-axis view), it is important to confirm that the catheter has been placed in the lumen of the blood vessel. This begins by confirmating that the guidewire has been advanced into the vessel lumen, as shown on the left in Figure 1.9 (16). The catheter can then be advanced over the guidewire, and the intraluminal placement of the catheter is then confirmed, as shown on the right in Figure 1.9.

INTRAOSSEOUS VASCULAR ACCESS

The discovery that fluids could be infused into the marrow cavity of bones and reach the systemic circulation occurred in the mid-1930s. However, this observation gained little attention until the London bombings during World War II, when the poor lighting from the frequent citywide blackouts created difficulties in establishing venous access, and an enterprising surgeon named Hamilton Bailey began infusing fluids into the marrow cavity of the sternum to resuscitate bombing victims (20). Despite early enthusiasm, the intraosseous (IO) route was relegated to obscurity when plastic catheters were introduced for intravenous cannulation (in the 1950s). A rebirth of the IO route occurred in the 1980s, when it was adopted for pediatric resuscitation, and it has subsequently gained favor in adults as an alternative route for emergency vascular access.

Indications

The principal indication for IO access is the need for emergent vascular access when intravenous (IV) access is problematic, or is not immediately available. This scenario is most likely to occur in patients with cardiac arrest, major trauma, or circulatory shock; in each of these conditions, IO access has proven to be a viable alternative to IV access (21−23). One appealing feature of the IO route is the rigid structure of the medullary cavity and its drainage system, which (unlike veins) will not collapse in the setting of hypotension, hypovolemia, or cardiovascular collapse.

Acceptance of the IO route is demonstrated in the most recent guidelines on advanced life support from the American Heart Association, which recommends proceeding to IO access when an initial attempt at IV access is unsuccessful, or IV access is not feasible (21). Since about two-thirds of cases of cardiac arrest occur outside the hospital (24), the need for IO access occurs primarily in the field. As a result, prehospital personnel (emergency medical technicians and paramedics) have been the major focus of training for IO access, and the success rate in the field is as high as 97% (25). IO access in the field is also important for the early management of major trauma (22), including combat casualties (25), and IO access is included in the knowledge base for Advanced Trauma Life Support (ATLS) certification from the American College of Surgeons (26).

Contraindications

Contraindications to IO access include a fractured or previously entered bone (because of possible leakage of infused fluids), vascular injury in the target extremity, and burn injury, cellulitis, or osteomyelitis at the cannulation site. Osteopetrosis (abnormally dense bone) is also a contraindication (23), but is a rare condition.

Establishing IO Access

There are two popular sites for IO access in adults: the proximal tibia (just below the knee), and the proximal humerus (just below the shoulder). The proximal tibia has two advantages: a higher success rate (25,27), and a location that does not interfere with intubation or chest compressions. The proximal humerus has the advantage of a higher flow capacity (28), but the proximal tibia is the favored site in adults.

The Proximal Tibia Site

The access site in the proximal tibia is on a flat surface of bone just below the medial condyle (see Figure 1.10). The point of needle insertion is 3 cm below the inferior tip of the patella, and 2 cm medial to that point.

Inserting the Needle

Inserting the IO needle can be done manually, but a powered “needle driver” is preferred. A popular choice in recent years is a battery-powered device like the one shown in Figure 1.10 (28,29). There are three different IO needles that attach to this device: each is a 15 gauge needle, available in lengths of 15 mm (for children), 25 mm (for average-sized adults), and 45 mm (for large or obese adults). The appropriate length for an individual patient can be determined by first advancing a probe needle until it hits the bone. (In awake patients, the probe needle should also be used to inject lidocaine locally, especially at the level of the periosteum, which is well endowed with pain fibers.) The IO needles have horizontal markers, and the measured distance from the skin to the periosteum should leave the horizontal marker closest to the hub of the needle at or slightly above the skin surface.

After appropriate skin antisepsis (sterile gloves are not required for inserting IO needles), the IO needle is advanced manually until it hits the bony surface of the tibia. The needle driver is then attached and, with the needle at an angle of 90° from the skin surface, the needle driver is engaged. This will spin the needle in a clockwise direction, and the needle is then advanced while applying downward pressure, until a sudden loss of resistance indicates entry into the medullary cavity. This should be verified by the aspiration of blood. This is not always possible, because bone marrow is viscous (like a jelly), which can prevent the aspiration of blood. Flushing the needle with 5–10 mL of saline can liquify enough marrow to correct this problem.

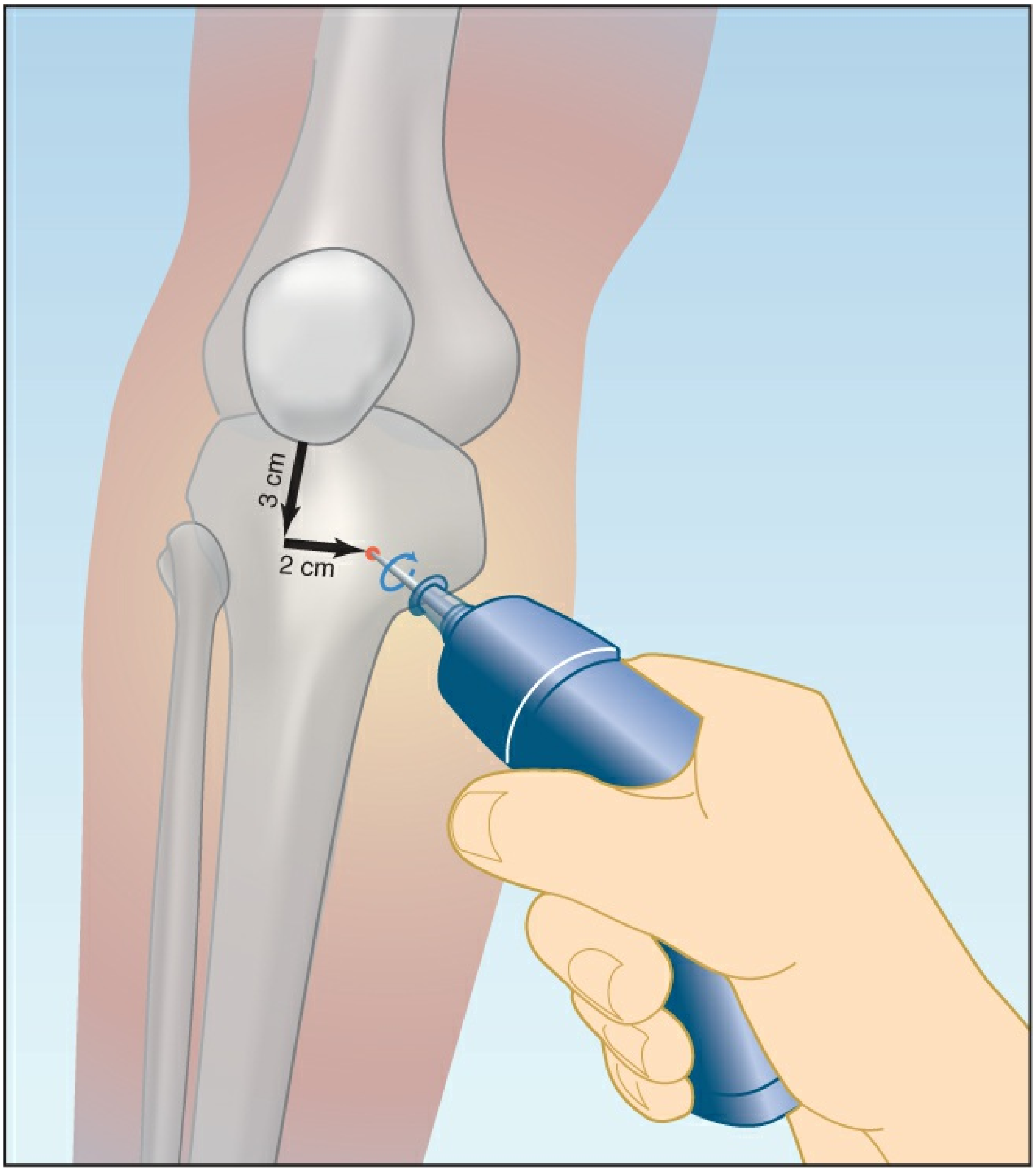

FIGURE 1.10 Illustration depicting the insertion of an intraosseous needle into the proximal femur, of the right leg and the surface measurements used to identify the insertion point. A battery powered needle driver is used to advance the needle into the marrow cavity. See text for further explanation.

Pre-Infusion Pain Control

The infusion of fluids into the marrow cavity is painful, presumably from stretching the periosteum. Therefore in awake patients, lidocaine injection into the medullary cavity is advised prior to infusing fluids. The recommended protocol is as follows (23,30):

. Use a 2% solution (20 mg/mL) of preservative-free lidocaine for intravenous use, and inject 40 mg (2 mL) into the marrow cavity over 2 minutes.

. Allow lidocaine to dwell for one minute, then flush with 10 mL of saline.

. Start the desired IO infusion. If pain relief is incomplete, readminister lidocaine at half the initial dose (20 mg) over one minute.

The lidocaine effect may be lost after one hour, and additional analgesia may be necessary. Intraosseous fentanyl (in the usual IV doses) can be used for this purpose.

IO Infusions

Intraosseous infusions are relatively sluggish, with flow rates that are about 25% of peripheral vein infusions (22,23). This is due to the viscous nature of bone marrow, and the relatively high pressure in the marrow cavity (which averages about 30 mm Hg). To counter the sluggish flow rates, IO infusions are routinely pressurized (with infusion pumps or inflatable pressure bags). However, pressures of 300 mm Hg or even higher may be inadequate for replacing massive blood loss, and dual IO infusions have been advocated by some in this situation (22).

Intraosseous access is considered a temporary intervention, and IO infusions are not recommended for longer than 24 hours (26). (There is, however, no firm evidence to validate this recommendation.) When IO infusions are discontinued, the IO needle is removed by attaching a luer-lock syringe and slowly rotating the needle in a clockwise direction as it is pulled upward at a 90° angle with the skin surface. (Rocking the needle back and forth to facilitate removal is not advised, and will promote leakage from the bone.)

Complications

Complications of IO access are infrequent (possibly due to its limited lifespan), with several studies showing complication rates below 1% (22,23). Potential complications include skin abscesses, osteomyelitis, tibial fracture, compartment syndrome, and fat or marrow emboli (22,23,30,31).

A FINAL WORD

One of the rarest sights in any ICU is a patient with no intravenous access. While this may not be a revelation, it does indicate that a working knowledge of vascular access has universal relevance for patient care in the ICU. This chapter is a first step in acquiring that knowledge. The following points in the chapter deserve emphasis.

- Infusion rates are influenced by the dimension of a vascular catheter, not by the size of the cannulated vein.
- The radius (lumen size) of a catheter has a much greater influence on flow than the length of the catheter. For rapid infusions, a large bore catheter is desirable, and a short, large-bore catheter is optimal.
- Midline catheters (15 – 20 cm catheters inserted into one of the major veins above the antecubital fossa) have become a popular choice for extended venous access, and can be used for prolonged vasopressor infusions.
- Real-time ultrasonography has become an essential tool for cannulating veins that are not visible or palpable.

. The intraosseous (IO) route is recommended for emergency vascular access when intravenous access is problematic, or not immediately available. The proximal femur is a popular site for IO access because the procedure does not interfere with intubation or chest compressions.

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Chapter 2

Central Venous Access

Good doctors leave good tracks.

J. Willis Hurst, MD ([*a*])

As a medical student in the early 1970s, I recall that vascular access was achieved almost exclusively by inserting narrow-bore needles into superficial veins in the arms (or wherever we could find them). The practice of inserting flexible plastic catheters into larger, more centrally placed veins was in its infancy (e.g., cannulation of the internal jugular vein was introduced only a few years earlier, in 1969) (1), and the procedure was often performed in the operating room, using a skin incision to introduce the (single-lumen) catheters, and forceps to advance the catheters through the subcutaneous tissues.

Now fast forward to modern times, and central venous access is a staple of patient care in ICUs, with multilumen catheters inserted percutaneously at the bedside, using real-time ultrasonography to guide the cannulation process (as described in Chapter 1). Central venous cannulation has become an essential skill for the care of critically ill patients, and this chapter will supplement the procedural skill (which must be acquired at the bedside) by presenting the relevant considerations involved in establishing central venous access.

CONSIDERATIONS IN PREVENTION

Central venous catheters have risks that far outweigh those of peripheral vein catheters (2), so the decision to insert a central venous catheter has implications for patient safety. There are, however, safer alternatives to central venous catheters in certain situations, as described next.

Shrinking Indications

The following are the traditional indications for inserting a central venous catheter.

- When peripheral venous access is difficult to obtain or maintain.
- For prolonged venous access (i.e., more than a few days).
- When multiple intravenous therapies are required (taking advantage of the multilumen

capabilities of central venous catheters).

- For the infusion of vasopressors, hypertonic fluids (including total parenteral nutrition), or vesicants (e.g., antineoplastic agents).
- For patients with life-threatening hemodynamic instability.
- For specialized interventions, such as acute hemodialysis, temporary transvenous pacing, or invasive hemodynamic monitoring.

It is now possible to avoid central venous access for many of the traditional indications, thanks to the emergence of midline catheters and peripherally inserted central catheters (PICCs). These catheters are described in Chapter 1. Both are inserted in the arm, just above the antecubital fossa (see Figure 1.3), and both can be used for prolonged venous access (especially PICCs, which can remain in place for months), and for infusions of vasopressors and hypertonic fluids (3). These catheters are also available with multiple lumens, for patients who require multiple intravenous therapies. Central venous access is still preferred for patients with life-threatening hemodynamic instability (circulatory shock), and it is mandatory for specialized interventions like acute hemodialysis. Thus, 4 of the 6 traditional indications for central venous access have alternative solutions.

Midline catheters and PICCs have fewer risks than central venous catheters (e.g., there is no risk of pneumothorax because the catheters are inserted in the arm) and they are more readily accepted by patients. Because of these advantages, the demand for central venous catheters is steadily declining (4), and midline catheters are becoming the preferred replacement (5).

Contraindications

There are no absolute contraindications to central venous cannulation, including the presence or severity of a coagulation disorder (6,7). There is a recommendation to correct a platelet count that is <20,000 x 10^6/L or an INR >3 prior to catheter insertion (7), but there is no evidence to support this recommendation.

Infection Control Measures

Infection control is an essential part of vascular cannulation, and the preventive measures recommended for central venous access are shown in Table 2.1 (8). When used together as a "bundle", these measures have been effective in reducing the incidence of catheter-related bloodstream infections (9–11). The following is a brief description of these preventive measures.

TABLE 2.1 The Central Line Insertion Bundle

Components	Recommendations
Hand Hygiene	Use an alcohol-based, waterless hand rub or a soap and water handwash before and after: a) palpating the catheter insertion site, or b) inserting, replacing, or manipulating the catheter..
Barrier Precautions	Use maximal barrier precautions, including cap, mask, sterile gloves, sterile gown, and sterile full body drape, for catheter insertion or guidewire exchange.
Skin Antisepsis	Scrub the insertion site with 2% chlorhexidine -70% alcohol solution for 30 seconds, and allow to dry completely..

Cannulation Site	When possible, avoid femoral vein cannulation.

From References 8–12.

Hand Hygiene

Proper hand hygiene is considered one of the most important, and most neglected, methods of infection control. Alcohol-based, waterless hand rubs are preferred, if available; otherwise, handwashing with soap (plain or antimicrobial soap) and water is acceptable (8,12). Hand hygiene should be performed before and after palpating catheter insertion sites, and before and after donning gloves to insert, replace, or manipulate catheters.

Skin Antisepsis

The catheter insertion site should be decontaminated just prior to cannulation, and the preferred antiseptic agent is chlorhexidine (usually in alcohol). This preference is based on clinical studies showing that chlorhexidine is superior to other antiseptic agents for limiting the risk of catheter-associated infections (13). The enhanced efficacy of chlorhexidine is attributed to its prolonged (≥6 hours) antimicrobial activity on the skin, which is maximized if allowed to air-dry on the skin (14). The drying time is typically 30 seconds for dry skin, and up to 2 minutes for moist skin (11).

Barriers

All vascular cannulation procedures, except those involving small peripheral veins, should be performed using full barrier precautions, which includes caps, masks, sterile gloves, sterile gowns, and a sterile drape from head to foot. (*Note*: The only barrier precaution advised for peripheral vein cannulation is the use of gloves, and nonsterile gloves are acceptable as long as the gloved hands do not touch the catheter) (8).

Site Selection

Cannulation of the femoral vein is considered the least desirable of the central venous access sites, primarily due to an increased risk of thrombosis with femoral vein catheters (15). When the central line bundle was introduced, there was also a higher risk of catheter-related septicemia with femoral catheters. However, *studies in more recent years have shown no increase in the risk of catheter-related septicemia with femoral catheters* (16). This is attributed to increased attention to infection control measures, and the current belief is that *the risk of catheter-related bloodstream infections is not related to the location of the insertion site, but rather to how the site is maintained* (in terms of infection control measures) (11).

INTERNAL JUGULAR VEIN

The most popular site for central venous access is the internal jugular vein at the base of the neck. The right side is preferred because the vessels run a relatively straight course, which reduces the risk of catheter misplacement.

Anatomy

The internal jugular vein (IJV) is located under the sternocleidomastoid muscle on either side of the neck, and it runs obliquely down the neck along a line drawn from the pinna of the ear to the sternoclavicular joint. In the lower neck region, the vein is typically located just anterior and lateral to the carotid artery (although anatomic relationships can vary), and both vessels run through the triangle created by the two heads of the sternocleidomastoid muscle (see Figure 2.1). At the base of the neck, the IJV and subclavian vein join to form the innominate vein, and the convergence of the right and left innominate veins forms the superior vena cava.

Cannulation Techniques

Positioning

Tilting the body so the head is below the horizontal plane (the Trendelenburg position) distends the IJV to facilitate cannulation, and increases venous pressure to reduce the risk of air embolism. In healthy subjects, a head-down body tilt to 15° is associated with a 20–25% increase in the diameter of the IJV, while greater degrees of tilt have no further effect (17). Thus, *only a limited (15°) body tilt is needed for IJV cannulation*. The head-down tilt is not necessary (and is usually not tolerated) in patients with venous congestion (e.g., from heart failure), and it is not advised in patients with increased intracranial pressure.

The head should be rotated slightly in the opposite direction to straighten the course of the vein. Excessive head rotation (beyond 40° from midline) pulls the IJV over the carotid artery, and this overlap increases the risk of carotid artery puncture (18). This risk is highlighted by evidence of posterior wall puncture in as many as 40% of ultrasound guided IJV cannulations (19).

Ultrasound Guidance

When real-time ultrasound is used to guide cannulation of the IJV, there is an increased success rate, fewer cannulation attempts, a shorter time to cannulation, and a reduced risk of carotid artery puncture (20). As a result, ultrasound guidance is a standard practice for catheterization of the IJV (21). (*Note:* The technique of ultrasound-guided vascular cannulation is described in Chapter 1.)

The IJV is well suited for ultrasound imaging because it is close to the skin, and there are no intervening structures to interfere with transmission of the ultrasound beam. A short-axis (cross-sectional) view of the IJV on the right side of the neck is shown in Figure 2.2. This image was obtained by placing the ultrasound probe at the apex of the triangle formed by the clavicular and sternal heads of the sternocleidomastoid muscle. (The probe should be oriented so it transects the muscle.) Note that the IJV is anterior and lateral to the carotid artery, and that there is some overlap of the vessels. This overlap creates the risk of carotid artery puncture, as explained earlier, and mandates that intraluminal placement of the catheter is confirmed. (See Figure 1.9.)

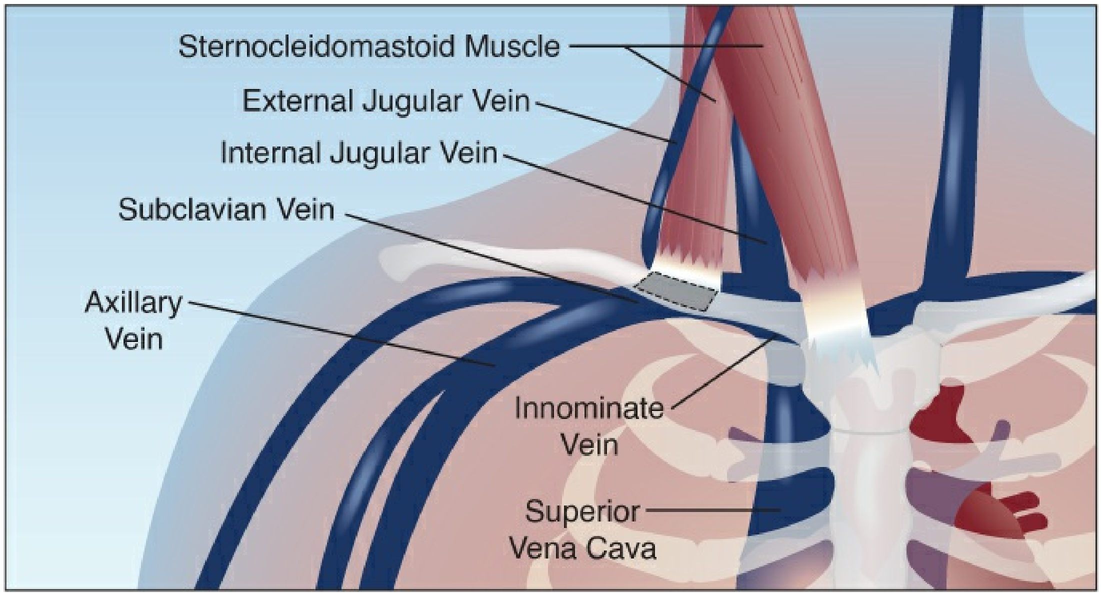

FIGURE 2.1 Anatomic relationships of the veins entering the thorax at the base of the neck.

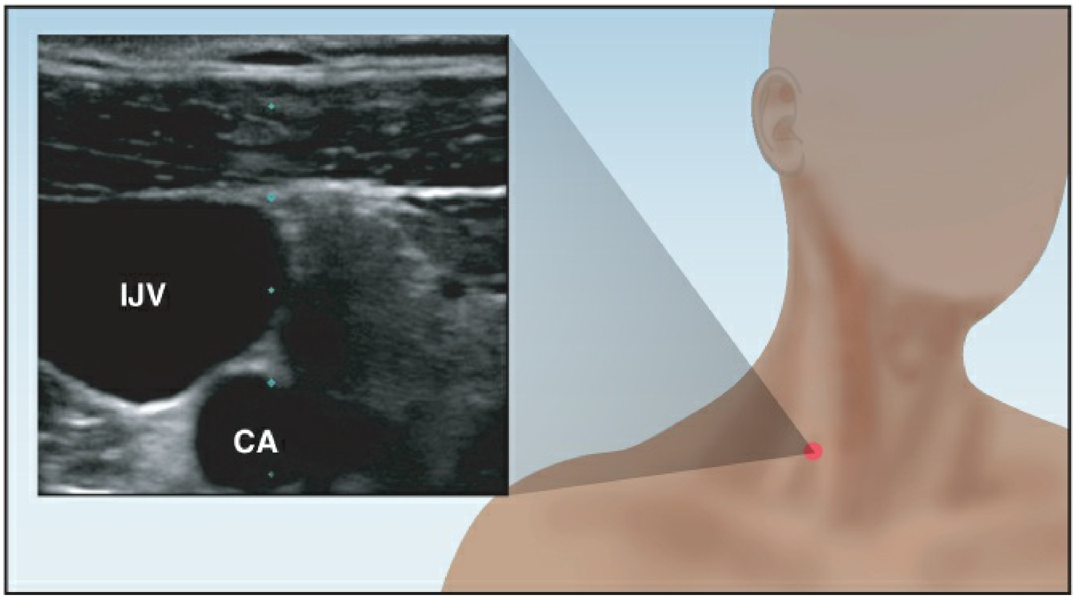

FIGURE 2.2 Short-axis view of the internal jugular vein (IJV) and carotid artery (CA), obtained by placing the ultrasound probe at the apex of the triangle formed by the two heads of the sternocleidomastoid muscle. The green dot marks the lateral side of the image. See text for further explanation.

Landmark Method

When ultrasound imaging is not available, cannulation of the IJV is guided by surface landmarks. There are two approaches using surface landmarks, as described next.

ANTERIOR APPROACH: For the anterior approach, the operator first identifies the triangular area at the base of the neck created by the separation of the two heads of the sternocleidomastoid muscle (see Figure 2.1). The IJV and carotid artery run through this triangle. The operator first locates the carotid artery pulse in this triangle; once the artery is located by palpation, it is gently retracted toward the midline and away from the IJV. The probe needle is then inserted at the apex of the triangle (with bevel facing up) and the needle is advanced toward the ipsilateral nipple at a 45° angle from the skin. If the vein is not entered by a depth of 5 cm, the needle should be drawn back and advanced again in a more lateral direction.

POSTERIOR APPROACH: For the posterior approach, the insertion point for the probe needle is 1 cm above the point where the external jugular vein crosses over the lateral edge of the sternocleidomastoid muscle. The probe needle is inserted at this point (with the bevel at 3 o'clock) and then advanced along the underbelly of the muscle in a direction pointing to the suprasternal notch. The internal jugular vein should be encountered 5 to 6 cm from the insertion point.

Complications

Accidental puncture of the carotid artery is the most feared complication of IJV cannulation. In a review of six randomized controlled trials of IJV cannulation by experienced operators, the summed incidence of carotid artery puncture was 9.2% when anatomic landmarks were used, and 1.8% with ultrasound guidance (20). If the carotid artery is punctured by the small-bore probe needle, it is usually safe to remove the needle and compress the site for at least 5 minutes (double the compression time for patients with a coagulopathy). Insertion of a catheter into the carotid artery is more of a problem because removing the catheter can be fatal (22,23). *If confronted with accidental cannulation of the carotid artery, leave the catheter in place and consult a vascular surgeon or interventional radiologist.*

TABLE 2.2 **Site-Specific Risks of Infection and Thrombosis**

	IJV	SV	FV
Number of Catheters	845	843	844
Bloodstream Infection	0.5%	1.4%	1.2%
Symptomatic DVT	0.5%	0.9%	1.4%

Data from Reference 15. IJV = internal jugular vein, SV = subclavian vein, FV = femoral vein.

Other mechanical complications (e.g., hemo/pneumothorax) are less common, and have an aggregated incidence of 2% when anatomic landmarks are used, and <1% with ultrasound guidance (20). Finally, the risk of catheter-related septicemia with IJV catheters is slightly higher than the risk with subclavian catheters (15), but the difference is small (0.5% vs 1.4%, see Table 2.2), and the infectious risk at both sites is considered equivalent (11).

SUBCLAVIAN VEIN

The subclavian vein was once the favored site for central venous access, but the emergence of ultrasound guidance has eroded its popularity because of interference from the overlying clavicle.

Anatomy

The subclavian vein is a continuation of the axillary vein as it passes over the first rib (see Figure 2.1). It runs most of its course along the underside of the clavicle (sandwiched between the clavicle and the first rib), and at some points is only 5 mm above the apical pleura of the lungs. The underside of the vein sits on the anterior scalene muscle along with the phrenic nerve, which comes in contact with the vein along its posteroinferior side. Situated just deep to the vein, on the underside of the anterior scalene muscle, is the subclavian artery and brachial plexus. At the thoracic inlet, the subclavian vein meets the internal jugular vein to form the innominate vein. The subclavian vein is 3–4 cm in length, and the diameter is 7–12 mm in the supine position (24). The diameter of the vein does not vary with respiration (unlike the IJV), which is attributed to strong fascial attachments that fix the vein to surrounding structures and hold it open (24). These attachments may also prevent collapse of the vein with volume depletion.

Cannulation Techniques

Positioning

The head-down body tilt (Trendelenburg position) to 15° increases the diameter of the subclavian vein by about 10%, with no further effect from greater degrees of tilt (14). Despite this minimal effect, the increase in venous pressure in the Trendelenburg position (which reduces risk of air embolism) has justified the recommendation for the head-down body tilt during subclavian vein cannulation (25). Other popular maneuvers (aimed at bringing the subclavian vein closer to the clavicle), such as turning the head or placing a rolled towel under the shoulder, are not advised because they decrease the cross-sectional area of the vein (24,26).

Ultrasound Guidance

The use of real time ultrasound improves the success rate of subclavian vein cannulation (from 82% to 97%) and decreases the complication rate (from 30% to 11%) (27). However as mentioned earlier, ultrasound imaging is a challenge for the subclavian vein because of interference from the overlying clavicle. The vein can be visualized from above or below the clavicle, but the infraclavicular approach is the popular choice.

INFRACLAVICULAR APPROACH: This approach begins by identifying the clavicular head of the sternocleidomastoid muscle and its insertion on the clavicle; this marks the portion of the clavicle that overlies the subclavian vein (as shown in Figure 2.1). Orient the ultrasound probe so it transects the clavicle (with the orientation marker pointing cephalad), and place the probe just below the lower edge of the clavicle in this region. This should produce a short-axis view like the image in Figure 2.3, which includes the subclavian vein and artery, as well as the apical pleura. Note the proximity of the subclavian vein to the apical pleura, highlighting the risk of pneumothorax during the cannulation procedure.

Identifying the subclavian vein by compression may not be possible because of the overlying clavicle, and color Doppler imaging may be necessary (see Figure 1.8). At the end of the cannulation procedure, the pleural line should be inspected for evidence of *lung sliding* to rule out iatrogenic pneumothorax (see later).

Landmark Method

To cannulate the subclavian vein without ultrasound, first mark the region of the clavicle that overlies the subclavian vein, as shown in Figure 2.1. The vein can be entered from above or below the clavicle in this region, but the infraclavicular approach is the popular route.

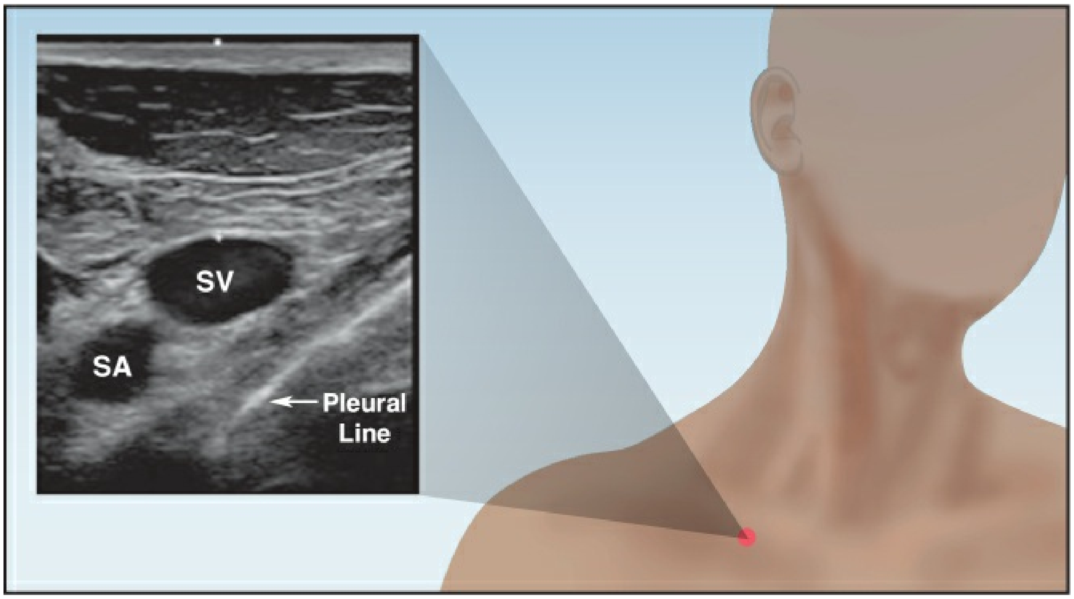

FIGURE 2.3 Infraclavicular, short-axis view of the subclavian vein (SV), subclavian artery (SA), and apical pleura, obtained by placing the ultrasound probe just below the clavicle in the region where it overlies the subclavian vein. See text for further explanation. Ultrasound image from Reference 25.

INFRACLAVICULAR APPROACH: At the lateral edge of the marked area, insert the probe needle (with the bevel at 12 o'clock) just below the clavicle, and advance the needle along the underside of the clavicle, in the direction of the suprasternal notch. The needle should enter the subclavian vein within a few centimeters. When the vein is punctured, turn the bevel to 3 o'clock to help direct the guidewire into the superior vena cava. It is important to keep the needle on the underside of the clavicle to avoid puncturing the subclavian artery (which lies deep to the subclavian vein) and the apical pleura.

In obese patients, the subclavian vein can be more deeply situated, and a deeper trajectory for the probe needle may be needed. This creates the risk for puncture of the subclavian artery or apical pleura. *In morbidly obese patients, the depth of the subclavian vein can exceed the reach of the probe needle* (26). For these reasons, the landmark approach to subclavian vein cannulation should be avoided, if possible, in morbidly obese patients.

Complications

The acute complications of subclavian vein cannulation (using ultrasound to landmark rates) include puncture of the subclavian artery (1% to 6%), pneumothorax (1% to 4%), brachial plexus injury (0% to 3%), phrenic nerve injury (0% to 2%), and catheter malposition (8% to 9%) (27). Complications associated with indwelling catheters include septicemia, thrombosis, and subclavian vein stenosis. The latter complication appears days or months after catheter removal, and has a reported incidence of 15–50% (28). The risk of stenosis is the principal reason to *avoid cannulation of the subclavian vein in patients who might require long-term hemodialysis access in the ipsilateral arm*.

FEMORAL VEIN

The femoral vein is considered the least desirable site for central venous access, although the unfavorable reputation is mostly undeserved (see later).

Anatomy

The femoral vein is a continuation of the long saphenous vein in the groin, and is the main conduit for venous drainage of the legs. It is located in the femoral triangle along with the femoral artery and nerve, as shown in Figure 2.4. The superior border of the femoral triangle is formed by the inguinal ligament, which runs from the anterior superior iliac spine to the pubic symphysis, just beneath the inguinal crease on the skin. At the level of the inguinal ligament (crease), the femoral vein lies just medial to the femoral artery, and is only a few centimeters from the skin. The vein is easier to locate and cannulate when the leg is placed in abduction.

Cannulation Techniques

Real-time ultrasound is recommended for femoral vein cannulation (21), although there is little evidence of benefit with ultrasound at this site (29).

Positioning

Elevation of the upper body to 15° above horizontal (the ”reverse” Trendelenburg position) can increase the cross-sectional area of the femoral vein by about 50% (30), so mild upper body elevation should be advantageous, especially for the landmark approach. Placing the leg in abduction is also recommended to facilitate the cannulation procedure.

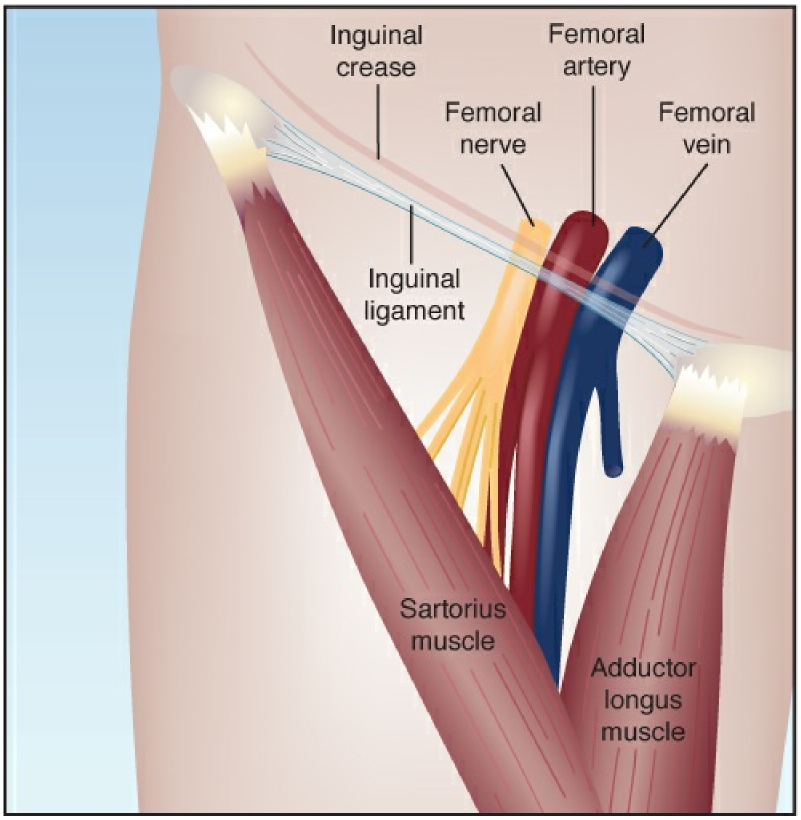

FIGURE 2.4 Anatomy of the femoral triangle.

Ultrasound Guidance

Ultrasound visualization of the femoral artery and vein is possible by placing the ultrasound probe over the femoral artery pulse, which is typically located just below and medial to the midpoint of the inguinal crease. A short-axis view of the femoral artery and femoral vein in this location is shown in Figure 1.8. Note that the vein lies a little deeper than the artery.

Landmark Method

To cannulate the femoral vein without ultrasound imaging, begin by locating the femoral artery pulse just below the inguinal crease. Then insert the probe needle (with the bevel at 12 o'clock) 1–2 cm medial to the pulse, and the vein should be entered at a depth of 2 to 4 cm from the skin. If the femoral artery pulse is not palpable, draw an imaginary line from the anterior superior iliac crest to the pubic tubercle, and divide the line into three equal segments. The femoral artery should be just underneath the junction between the middle and medial segments, and the femoral vein should be 1–2 cm medial to this point. This approach has a reported success rate of >90% (31).

Complications

The principal concerns at the femoral site are thrombosis and septicemia, which are considered enough of a risk to discourage femoral vein cannulation (as indicated in Table 2.1). However, study results like those in Table 2.2 (15) are not as foreboding as advertised. These results (from a multicenter study that included 2,532 central venous catheters) show a remarkably low rate of infectious and thrombotic complications at all sites. The risk of catheter-related septicemia at the femoral site was actually lower than the risk at the internal jugular vein site (the favored site for central venous access). The femoral site did have the highest risk of symptomatic deep vein thrombosis (DVT), but the overall risk was minor (1.5%). Results like these are supported by other studies (32), and they demonstrate the safety of the femoral vein site for central venous access.

IMMEDIATE CONCERNS

Venous Air Embolism

Air entry into the venous circulation is an uncommon but potentially lethal complication of central venous cannulation (33).

Pathophysiology

Pressure gradients that favor the movement of air into the venous circulation are created by the negative intrathoracic pressure generated during spontaneous breathing. A pressure gradient of only 5 mm Hg across a 14 gauge catheter (internal diameter = 1.8 mm) can entrain air at a rate of 100 mL per second, and this is enough to produce a fatal venous air embolism (34).

The impact of air entry into the venous circulation is determined by the volume of air and the rate of entry. The outcome can be fatal when air entry reaches 200–300 mL (3–5 mL/kg) over a few seconds (34). Entrained air can produce an air lock in the right ventricle, leading to acute right heart failure and cardiogenic shock, while air reaching the pulmonary circulation can produce leaky-capillary pulmonary edema (33,34). Finally, air can pass through a patent foramen ovale and produce an acute embolic stroke.

Prevention

The standard preventive measure for air embolism is the head-down body tilt (the Trendelenburg position) to increase venous pressure during cannulation of the internal jugular and subclavian veins. Elevation of the upper body (the reverse Trendelenburg position) is not necessary as a preventive measure during femoral vein cannulation because femoral vein catheters do not enter the thorax and thus are not exposed to negative pressures.

Clinical Presentation

Venous air entry can be clinically silent (33). In symptomatic cases. the earliest manifestation is sudden onset of dyspnea, which may be accompanied by a distressing cough. This can progress rapidly to acute respiratory failure and circulatory shock. In the most advanced cases, the mixing of air and blood in the right ventricle can produce a splashing auscultatory sound called a ‘mill wheel’ murmur (35).

Venous air embolism is usually a clinical diagnosis. Transesophageal echocardiography is considered the most sensitive method of detecting air in the right heart (capable of detecting as little as 0.02 mL/kg) (33), but this procedure is often not readily available. Precordial Doppler ultrasound can be useful (air in the cardiac chambers produces a high-pitched sound), but the Doppler signal can lack specificity (33).

Management

The following measures are recommended for the management of venous air embolism (33,34), although their efficacy is unproven.

- If air entrainment is suspected through an indwelling catheter, attach a syringe to the catheter and attempt to aspirate air from the bloodstream.
- Place the patient on 100% oxygen (to promote the movement of nitrogen out of the air bubbles in the bloodstream, and thereby decrease the volume of entrained air.
- Place the patient in the left lateral decubitus position (to move an air pocket that is blocking the outflow of the right ventricle).
- For patients with cardiovascular collapse, consider extracorporeal support.

Pneumothorax

Pneumothorax is a feared but infrequent complication of central venous access, and most cases are associated with subclavian vein cannulation (where the incidence is 1% using ultrasound and 4% otherwise) (27). The detection of post-procedure pneumothoraces can be problematic, as explained next.

Portable Chest Radiography

The portable chest x-ray has been the standard method for detecting pneumothorax after central venous cannulation, but clinical studies have shown that *portable chest x-rays fail to detect as many as 50% of pneumothoraces in critically ill patients* (36,37). This lack of sensitivity is attributed to the supine position (which is the position of most patients in the ICU during portable chest radiography), because pleural air does not collect at the apex of the lungs in the supine position, but instead collects in the anterior region of the pleural cavity (which can be close to the base of the lung) (38,39). Pleural air in this location will be in front of the lungs, and can be missed on a portable chest x-ray because of the lung markings behind the pleural air. An example of an anterior pneumothorax that is not apparent on a supine chest x-ray is shown in Figure 2.5.

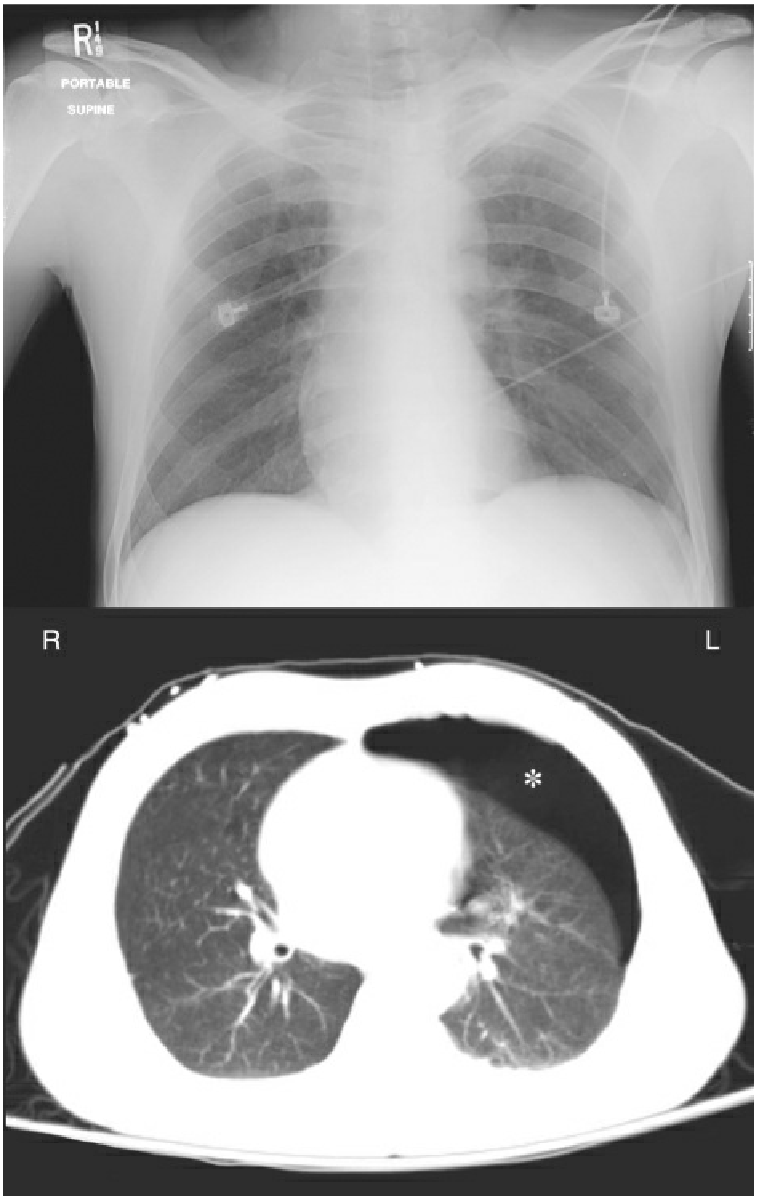

FIGURE 2.5 Portable chest x-ray and CT image of the chest in a young male with blunt chest trauma. The chest film is unrevealing, while the CT image shows an anterior pneumothorax (indicated by the asterisk).

Ultrasound

The pleura can be visualized on ultrasound imaging using a high-frequency, linear array probe (the same probe used for vascular ultrasound) that is placed across the intercostal spaces. The normal movement of the pleural surfaces creates a shimmering effect on the pleural image that is known as “lung sliding” (40). The absence of lung sliding then suggests the presence of a pneumothorax. Other conditions (e.g., blebs, pleurodesis) can be accompanied by the absence of lung sliding, so this sign is not pathognomonic of pneumothorax.

Several clinical studies have shown that ultrasound has a higher sensitivity than portable chest x-rays for the detection of pneumothoraces (36,37), including those associated with central venous cannulation (41). As a result, ultrasound has been recommended as a replacement for chest radiography after central venous cannulation.

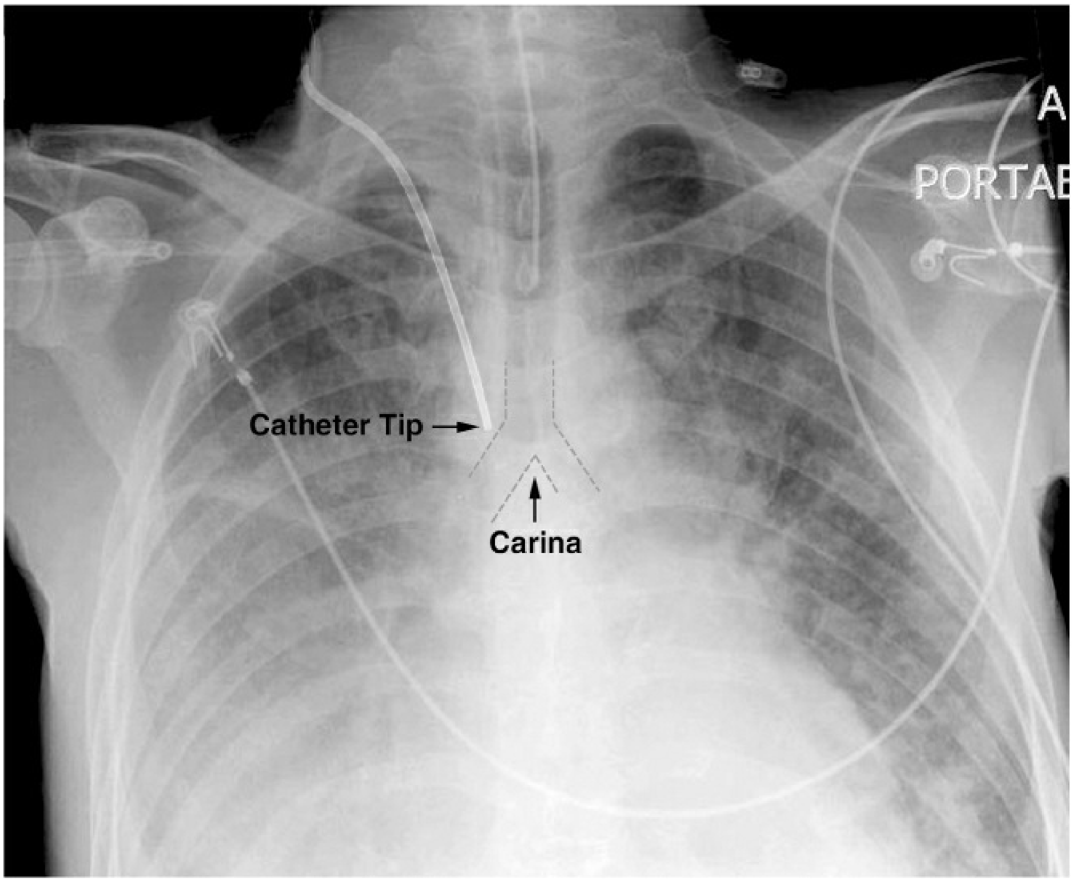

FIGURE 2.6 Portable chest x-ray showing the proper placement of a central venous catheter. Note that the tip of the catheter is at the level of the carina (i.e., the tracheal bifurcation, highlighted by the dotted lines), which lies just above the junction between the superior vena cava and right atrium. Image digitally enhanced

Catheter Position

Catheters inserted via the internal jugular and subclavian veins should be in the superior vena cava, with the tip 1–2 cm above the right atrium. Misplacement of catheters is reported in 15–18% of cannulations (41), mostly those involving the subclavian vein.

Chest Radiography

The standard practice is to evaluate catheter placement with a portable chest x-ray, and the one in Figure 2.6 shows a catheter that is appropriately placed. Note that the catheter follows a straight course down the mediastinum, and the tip of the catheter is just above the carina (i.e., the tracheal bifurcation). The carina is located just above the junction between the superior vena cava and the right atrium, so a catheter tip that is at the level of the carina, or slightly above it, is in the appropriate position. The carina is thus a useful landmark for evaluating catheter position (42).

Ultrasound

Ultrasound has been recommended as a replacement for chest radiography to evaluate catheter placement. There are two aspects of the ultrasound examination. The first pertains to subclavian vein catheters, and involves imaging the internal jugular vein on both sides to identify cephalad misplacement of the catheter (which must be corrected). This can be done during the catheterization procedure to save time in repositioning the catheter.

The second aspect of the ultrasound exam uses a phased array transducer in the subcostal window to visualize the catheter in the right atrium. If the catheter is not in the right atrium, then a "bubble study" is performed. This involves the rapid injection of 10 ml of saline through the distal port of the catheter, and observing for the appearance of microbubbles in the right atrium. A positive test confirms that the catheter is in the venous system, while the appearance of the bubbles within 2 seconds of injection is evidence that the catheter tip is in the superior vena cava (43).

Catheter Tip in Right Atrium

Catheters that have been advanced into the right atrium have traditionally been repositioned because of the perceived risk of right atrial perforation and cardiac tamponade. However, this practice is being questioned because of the rarity of this complication (44). In one study that included 2,348 patients with a catheter tip that remained in the right atrium, there were no cases of cardiac perforation or troublesome cardiac arrythmias (45). As a result of studies like this, the practice of repositioning catheters that enter the right atrium is being abandoned.

A FINAL WORD

The following points related to central venous access deserve emphasis.

- The indications for central venous access are shrinking, thanks to the emergence of safer alternatives like midline catheters and peripherally inserted central catheters (PICCs).
- The use of real-time ultrasound improves the success rate, and reduces the complication rate, at all sites of central venous access.
- The perception that femoral vein catheters are particularly risky is not supported by clinical studies (see Table 2.2).
- Ultrasound is superior to portable chest radiography for detecting post-insertion pneumothoraces, and is a suitable alternative to chest radiography for evaluating catheter position.
- Catheters that have been advanced into the right atrium pose no great danger of cardiac perforation, and can be left in place.

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