review article

current concepts

Preventing Complications of Central Venous Catheterization

David C. McGee, M.D., and Michael K. Gould, M.D.

In the United States, physicians insert more than 5 million central venous catheters every year.[1] Central venous catheters allow measurement of hemodynamic variables that cannot be measured accurately by noninvasive means and allow delivery of medications and nutritional support that cannot be given safely through peripheral venous catheters. Unfortunately, the use of central venous catheters is associated with adverse events that are both hazardous to patients and expensive to treat.[2-4] More than 15 percent of patients who receive these catheters have complications.[5-7] Mechanical complications are reported to occur in 5 to 19 percent of patients,[5,6,8] infectious complications in 5 to 26 percent,[5,7,9] and thrombotic complications in 2 to 26 percent.[5] In this review, we explain methods for reducing the frequency of complications in adult patients.

From the Division of Pulmonary and Critical Care Medicine (D.C.M., M.K.G.), the Department of Health Research and Policy (M.K.G.), and the Center for Primary Care and Outcomes Research (M.K.G.), Stanford University School of Medicine, Stanford, Calif.; and the Health Services Research and Development Service and Center for Health Care Evaluation, Veterans Affairs Palo Alto Health Care System, Palo Alto, Calif. (M.K.G.). Address reprint requests to Dr. Gould at the Pulmonary and Critical Care Section (111P), Veterans Affairs Palo Alto Health Care System, 3801 Miranda Ave., Palo Alto, CA 94304.

N Engl J Med 2003;348:1123-33.

types of catheters

antimicrobial-impregnated catheters

Catheters impregnated with chlorhexidine and silver sulfadiazine and catheters impregnated with minocycline and rifampin are the most frequently used types of antimicrobial-impregnated catheters. In randomized clinical trials, the use of these catheters has been shown to lower the rate of catheter-related bloodstream infections[9,10] (Table 1). The use of catheters impregnated with chlorhexidine and silver sulfadiazine lowered the rate of catheter-related bloodstream infections from 7.6 infections per 1000 catheter-days (4.6 percent of catheters) to 1.6 infections per 1000 catheter-days (1.0 percent) (relative risk, 0.21; 95 percent confidence interval, 0.03 to 0.95; P=0.03).[10] A cost-effectiveness analysis concluded that using these catheters would decrease direct medical costs by $196 per catheter inserted.[11]

The use of antimicrobial-impregnated catheters should be considered in all circumstances, especially when the institutional rate of catheter-related bloodstream infections is higher than 2 percent, which is the threshold at which chlorhexidine-and-silver-sulfadiazine–impregnated catheters may reduce overall costs.[10] Current evidence suggests that minocycline-and-rifampin–impregnated catheters are even more effective for minimizing the risk of infection than those that are impregnated with chlorhexidine and silver sulfadiazine.[29] However, this evidence comes from a single randomized trial, and the cost effectiveness of these catheters relative to those that are impregnated with chlorhexidine and silver sulfadiazine has not been formally evaluated. Thus, either chlorhexidine-and-silver-sulfadiazine–impregnated catheters or minocycline-and-rifampin–impregnated catheters may be used.

The emergence of resistant organisms resulting from the use of antimicrobial-impregnated catheters remains a potentially important concern. Continued surveillance will be needed as the use of antimicrobial-impregnated catheters increases.

Table 1. Interventions to Prevent Complications.

Type of Complication and Intervention	Rationale
Infectious	
Use antimicrobial-impregnated catheters	The use of antimicrobial-impregnated catheters reduces the risk of catheter-related bloodstream infections and reduces costs when the rate of catheter-related bloodstream infection >2%[9-11]
Insert catheters at the subclavian venous site	The risk of catheter-related infection is lower with subclavian catheterization than with internal jugular or femoral catheterization[5,9,12,13]
Use maximal sterile-barrier precautions during catheter insertion	Use of a mask, cap, sterile gown, sterile gloves, and large sterile drape reduces the rate of infections and reduces costs[14]
Avoid the use of antibiotic ointments	The application of antibiotic ointments increases the rate of colonization by fungi,[15] promotes the development of antibiotic-resistant bacteria,[16] and has not been shown to affect the risk of catheter-related bloodstream infections[17]
Disinfect catheter hubs	Catheter hubs are common sites of catheter contamination[18]
Do not schedule routine catheter changes	Scheduled, routine replacement of central venous catheters at a new site does not reduce the risk of catheter-related bloodstream infection[19,20]; scheduled, routine exchange of catheters over a guide wire is associated with a trend toward increased catheter-related infections[19]
Remove catheters when they are no longer needed	The probability of colonization and catheter-related bloodstream infection increases over time[9,10,21]
Mechanical	
Recognize risk factors for difficult catheterization	A history of failed catheterization attempts or the need for catheterization at sites of prior surgery, skeletal deformity, or scarring suggests that catheterization may be difficult[8]
Seek assistance from an experienced clinician	Insertion by a physician who has performed ≥50 catheterizations is half as likely to result in a mechanical complication as insertion of a catheter by a physician who has performed <50 catheterizations[6]
Avoid femoral venous catheterization	The frequency of mechanical complications with femoral catheterization is higher than with subclavian or internal jugular catheterization[5,6,8,22-24]; the rates of serious complications are similar with the femoral and subclavian approaches[5]
Use ultrasound guidance during internal jugular catheterization	The use of ultrasound guidance during internal jugular catheterization reduces the time required for insertion and reduces the rates of unsuccessful catheterization, carotid-artery puncture, and hematoma formation[25,26]
Do not schedule routine catheter changes	Scheduled, routine replacement of catheters at new sites increases the risk of mechanical complications[19,27]
Thrombotic	
Insert the catheter at the subclavian site	Subclavian catheterization carries a lower risk of catheter-related thrombosis than femoral or internal jugular catheterization[5,28]

SINGLE-LUMEN AND MULTILUMEN CATHETERS

The number of lumina does not directly affect the rate of catheter-related complications.[30-32] Therefore, the choice of either a single-lumen or a multilumen catheter should be made according to the type required to deliver the needed medications or nutritional support.

INSERTION SITES

CHARACTERISTICS OF PATIENTS

There are multiple approaches for internal jugular, subclavian, and femoral venous catheterization.[33] Successful catheterization by either the internal jugular or the subclavian route relies on a thorough understanding of the anatomy of the neck (Fig. 1). The internal jugular vein is located at the apex of the triangle formed by the heads of the sternocleidomastoid muscle and the clavicle. The subclavian vein crosses under the clavicle just medial to the midclavicular point. When it is difficult to identify the landmarks for one type of catheterization, another route should be considered. All patients should be assessed for factors that might increase the difficulty of catheter insertion, such as a history of failed catheterization attempts or the need for catheterization at a site of previous surgery, skeletal deformity, or scarring.[8] When a difficult catheterization is anticipated, the importance of patient safety dictates that the procedure be performed or supervised by an experienced physician.

Internal jugular catheterization can be difficult in morbidly obese patients, in whom the landmarks of the neck are often obscured. Subclavian venous catheterization should be avoided in patients with severe hypoxemia, because the complication of pneumothorax is more likely to occur at this site and is less likely to be tolerated by such patients. Femoral catheterization should be avoided in patients who have grossly contaminated inguinal regions because femoral insertion places these patients at high risk for the development of catheter-related infections. If central venous access is needed for resuscitation from shock, femoral venous access should be considered because of the speed with which it can be performed, especially if it is believed that internal jugular or subclavian venous catheterization will be difficult. After resuscitation, the catheter can be replaced at the most appropriate site for the patient.

MECHANICAL COMPLICATIONS

Arterial puncture, hematoma, and pneumothorax are the most common mechanical complications during the insertion of central venous catheters (Table 2). Overall, internal jugular catheterization and subclavian venous catheterization carry similar risks of mechanical complications. Subclavian catheterization is more likely than internal jugular catheterization to be complicated by pneumothorax and hemothorax, whereas internal jugular catheterization is more likely to be associated with arterial puncture. Hematoma and arterial puncture are common during femoral venous catheterization. Because mechanical complications are most likely during catheterization at the femoral site, the internal jugular or subclavian venous route should be chosen unless contraindicated. However, the rate of serious mechanical complications (e.g., pneumothorax requiring insertion of a chest tube or hemorrhage requiring blood transfusion or surgery) associated with subclavian insertion is similar to that associated with femoral insertion.[5]

INFECTIOUS COMPLICATIONS

Catheter-related infections are thought to arise by several different mechanisms: infection of the exit site, followed by migration of the pathogen along the external catheter surface; contamination of the catheter hub, leading to intraluminal catheter colonization; and hematogenous seeding of the catheter. A randomized trial found that subclavian venous catheterization was associated with a significantly lower rate of total infectious complications than femoral venous catheterization and a trend toward a lower rate of suspected or confirmed catheter-related bloodstream infections (1.2 infections per 1000 catheter-days, vs. 4.5 infections per 1000 with femoral catheterization; $P=0.07$).[5] Available evidence suggests that subclavian catheterization is less likely to result in catheter-related infection than internal jugular catheterization, although the two approaches have not been compared in randomized trials.[9,12,13] Thus, selection of the subclavian site appears to minimize the risk of infectious complications.

THROMBOTIC COMPLICATIONS

Patients who require central venous catheterization are at high risk for catheter-related thrombosis. Used routinely, ultrasonography with color Doppler imaging detects venous thrombosis in 33 percent of patients in medical intensive care units[34] and in approximately 15 percent of these patients the thrombosis is catheter-related. The risk of catheter-related thrombosis varies according to the site of insertion. In one trial, catheter-related thrombosis occurred in 21.5 percent of the patients with femoral venous catheters and in 1.9 percent of those with subclavian venous catheters ($P<0.001$).[5] In an observational study, the risk of thrombosis associated with internal jugular insertion was approximately four times the risk associated with subclavian insertion.[28] Subclavian venous catheterization carries the lowest risk of catheter-related thrombosis. The clinical importance of catheter-related thrombosis remains undefined, although all thromboses have the potential to embolize.

A

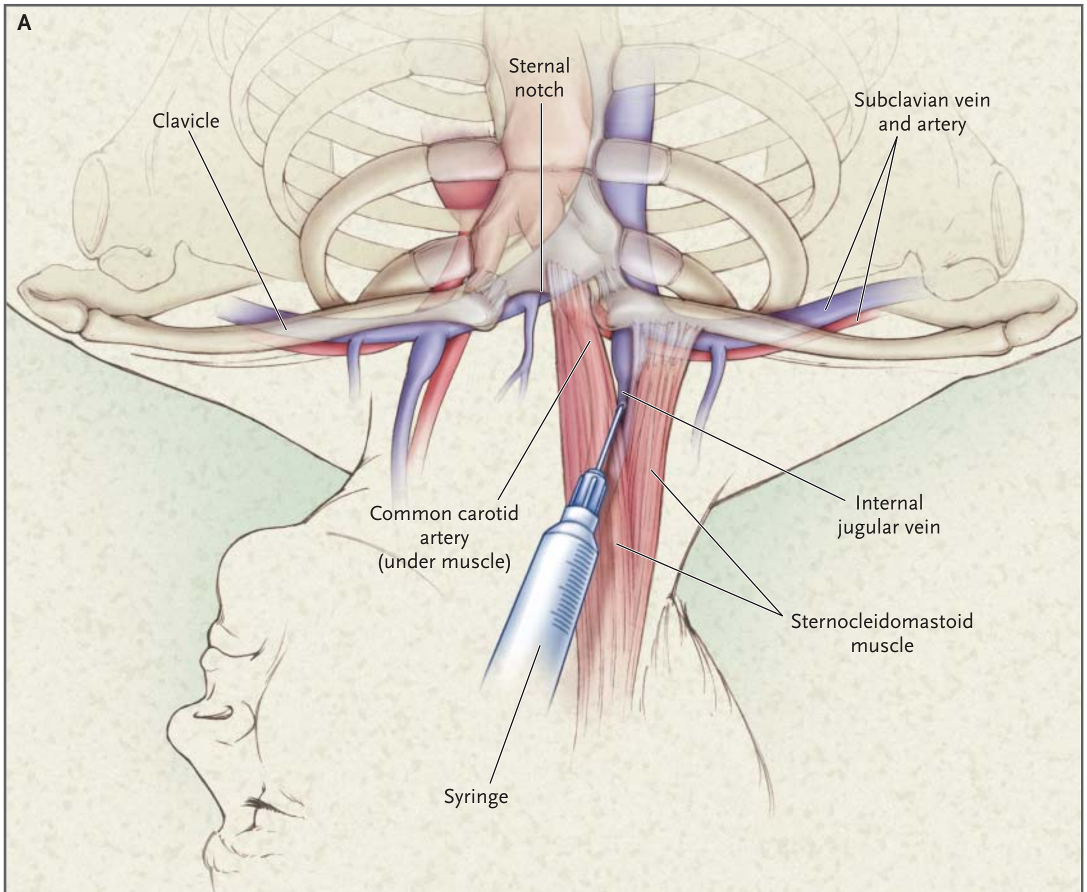
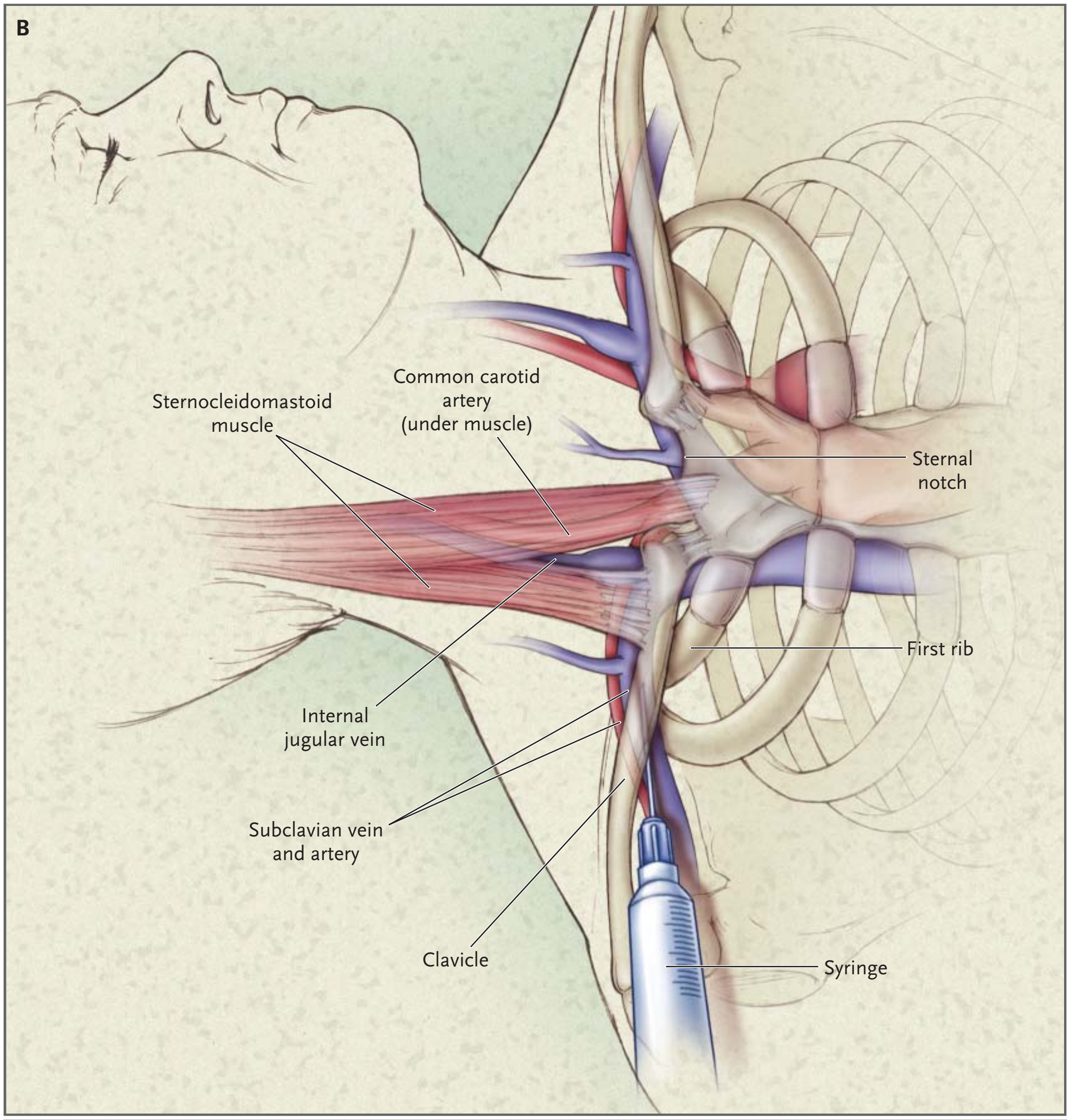


Figure 1. Technique for Catheterization at the Internal Jugular and Subclavian Sites.

In the central approach for internal jugular venous catheterization (Panel A), the apex of the triangle formed by the two heads of the sternocleidomastoid muscle and the clavicle serves as a landmark. The internal jugular vein runs deep to the sternocleidomastoid muscle and then through this triangle before it joins the subclavian vein to become the brachiocephalic vein. After the landmarks have been identified, sterile barriers have been prepared, and local anesthesia has been administered, the patient is placed in Trendelenburg's position with the head rotated 45 degrees away from the site of cannulation. The physician places the index and middle finger of his or her nondominant hand on the carotid artery and inserts a 22-gauge "finder" needle through the skin, immediately lateral to the carotid pulse and slightly superior to the apex of the triangle. The needle is advanced past the apex of the triangle, in the direction of the ipsilateral nipple, at an angle of 20 degrees above the plane of the skin. The vein is usually located near the surface of the skin and is often encountered after less than 0.5 in. (1.3 cm) of the needle has been inserted. If the first pass is unsuccessful, the needle should be directed slightly more medially on the next insertion attempt. With the finder needle in place, an 18-gauge introducer needle is then inserted alongside it and into the vein.

In the infraclavicular approach for subclavian venous catheterization (Panel B, facing page), the subclavian vein arises from the axillary vein at the point where it crosses the lateral border of the first rib. It is usually 1 to 2 cm in diameter and is fixed in position directly beneath the clavicle. It is separated from the subclavian artery by the anterior scalene muscle. For catherization, the patient is placed in Trendelenburg's position, and a small rolled towel is placed between the shoulder blades. After identification of the landmarks, sterile preparation, and administration of local anesthesia, the skin is punctured 2 to 3 cm caudal to the midpoint of the clavicle with an 18-gauge, 2.5-in. (6.3-cm) introducer needle. The needle is advanced in the direction of the sternal notch until the tip of the needle abuts the clavicle at the junction of its medial and middle thirds. The needle is then passed beneath the clavicle, with the needle hugging the inferior surface of the clavicle. If no blood returns with passage of the needle, the needle is withdrawn past the clavicle while gentle suction is applied. Blood return may be achieved during withdrawal of the needle. If the first pass is unsuccessful, the needle should be angled in a slightly more cephalad direction on the next insertion attempt.



INSERTION TECHNIQUE

PREPARATION

When inserting a catheter, one should use maximal sterile-barrier precautions, including a mask, a cap, a sterile gown, sterile gloves, and a large sterile drape. This approach has been shown to reduce the rate of catheter-related bloodstream infections and to save an estimated $167 per catheter inserted.[14] The use of chlorhexidine-based solutions for skin preparation may be preferable to the use of povidone–iodine solutions, because chlorhexidine reduces the risk of catheter colonization.[35,36] A video that shows the insertion of catheters at the internal jugular and sub-

Table 2. Frequency of Mechanical Complications, According to the Route of Catheterization.*

Complication	Frequency		
	Internal Jugular	Subclavian	Femoral
		percent	
Arterial puncture	6.3–9.4	3.1–4.9	9.0–15.0
Hematoma	<0.1–2.2	1.2–2.1	3.8–4.4
Hemothorax	NA	0.4–0.6	NA
Pneumothorax	<0.1–0.2	1.5–3.1	NA
Total	6.3–11.8	6.2–10.7	12.8–19.4

* Data are from Merrer et al.,[5] Sznajder et al.,[6] Mansfield et al.,[8] Martin et al.,[22] Durbec et al.,[23] and Timsit et al.[24] NA denotes not applicable.

Table 3. Types of Catheter-Associated Infections.*

Type	Description
Catheter colonization	Growth of organisms from a catheter segment by either semiquantitative or quantitative culture†
Catheter-related bloodstream infection	Isolation of the same organism from a blood culture and from a semiquantitative or quantitative culture of a catheter segment, accompanied by clinical symptoms of bloodstream infection without any other apparent source of infection‡
Exit-site infection	Erythema, tenderness, induration, or purulence within 2 cm of the exit site of the catheter

* Information is adapted from Pearson.[44]

† In the semiquantitative culture technique,[57] the catheter segment is rolled on a culture plate, which is observed for colony formation; the growth of ≥15 colony-forming units defines colonization. In the quantitative technique,[58-60] the catheter segment is processed in broth and sonicated, and the broth is surface-plated onto a culture plate; the growth of 1000 or more colony-forming units defines colonization.

‡ For the prediction of catheter-related bloodstream infections in patients without burns, the semiquantitative culture technique has a sensitivity of 86 percent, a specificity of 88 percent, a positive predictive value of 33 percent, and a negative predictive value of 99 percent.[60] The quantitative culture technique has a sensitivity of 89 percent, a specificity of 94 percent, a positive predictive value of 73 percent, and a negative predictive value of 98 percent.[60]

clavian sites is available as Supplementary Appendix 1 with the full text of the article at http://www.nejm.org.

EXPERIENCE WITH CATHETERIZATION

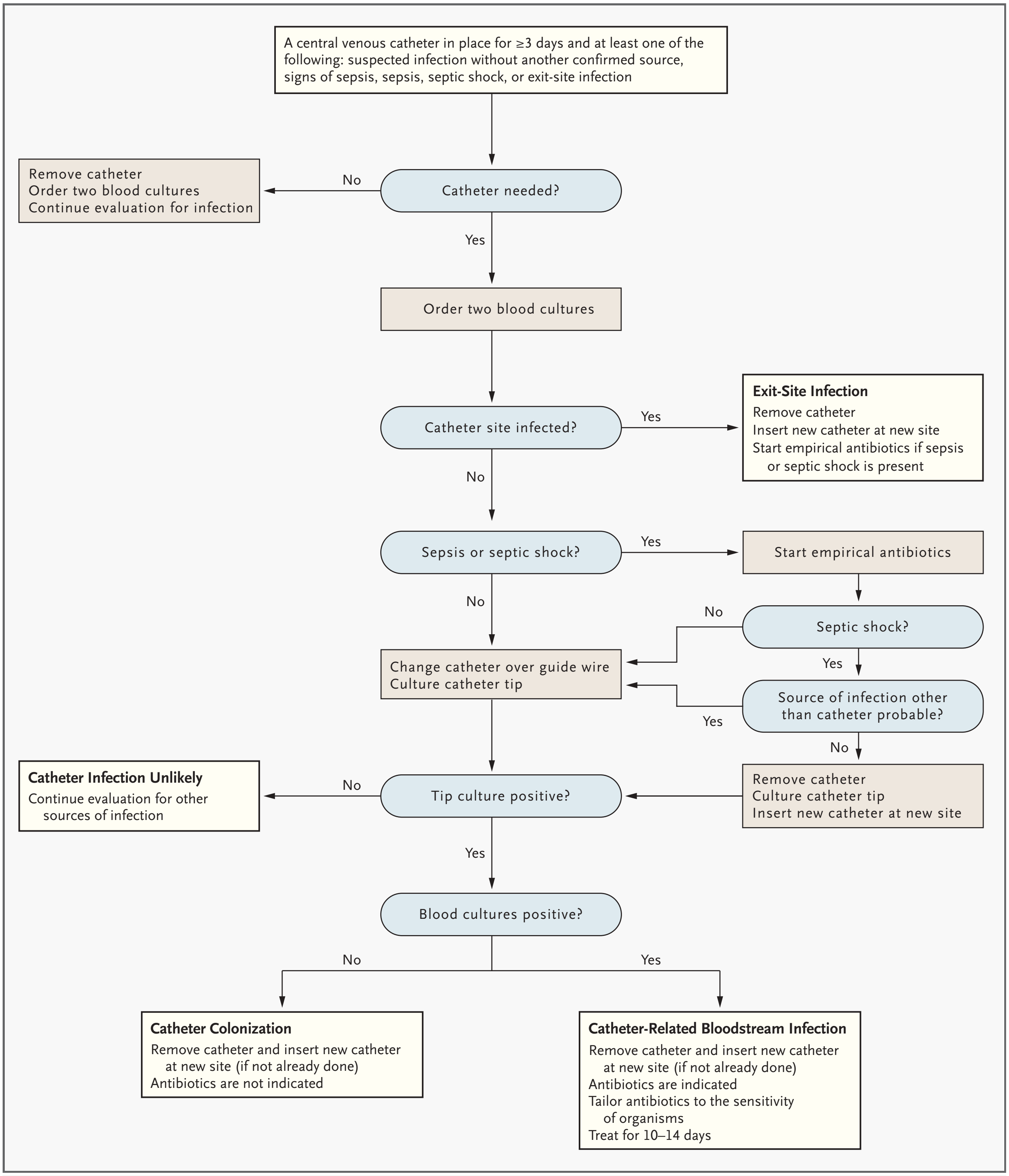
As with most medical procedures, the level of experience of the physician reduces the risk of complications.[6,37] Insertion of a catheter by a physician who has performed 50 or more catheterizations is half as likely to result in a mechanical complication as insertion by a physician who has performed fewer than 50 catheterizations.[6] If a physician is unable to insert a catheter after three attempts, he or she should seek help rather than continue to attempt the procedure. The incidence of mechanical complications after three or more insertion attempts is six times the rate after one attempt.[8]

ULTRASOUND GUIDANCE

The use of ultrasound guidance has been promoted as a method for reducing the risk of complications during central venous catheterization. In this technique, an ultrasound probe is used to localize the vein and to measure its depth beneath the skin. Under ultrasound visualization, the introducer needle is then guided through the skin and into the vessel. During internal jugular venous catheterization, ultrasound guidance reduces the number of mechanical complications, the number of catheter-placement failures, and the time required for insertion.[25,26] However, its use during subclavian venous catheterization has had mixed results in clinical trials,[26,38,39] probably for anatomical reasons. The fixed anatomical relation between the subclavian vein and the clavicle makes ultrasound-guided catheter insertion more difficult and less reliable than landmark-based insertion. As with all new techniques, ultrasound-guided catheterization requires training. In hospitals where ultrasound equipment

Figure 2 (facing page). Management of Suspected Catheter-Related Bloodstream Infection.

Sepsis is defined as a systemic response to infection, manifested by two or more of the following conditions: temperature above 38.5°C or below 36.0°C; heart rate above 90 beats per minute; respiratory rate above 20 breaths per minute or partial pressure of arterial carbon dioxide below 32 mm Hg; and white-cell count greater than 12,000 per cubic millimeter or less than 4000 per cubic millimeter or with 10 percent immature (band) forms.[61] Septic shock is defined as sepsis-induced hypotension or a requirement for vasopressors or inotropic agents to maintain blood pressure despite adequate fluid resuscitation, along with the presence of perfusion abnormalities that may include (but are not limited to) lactic acidosis, oliguria, or acute alteration in mental status.[61] When blood cultures are obtained, samples from peripheral sites are preferred. Catheter-tip cultures should be performed by the semiquantitative or quantitative technique.[27,62,63] Empirical antibiotic therapy for suspected catheter-related bloodstream infection should include vancomycin. Antibiotics that are effective against gram-negative organisms should be added, especially if the patient is immunocompromised or has neutropenia, is infected with gram-negative organisms, or has other risk factors for infection with gram-negative organisms. In patients with a catheter-related bloodstream infection, treatment for more than 14 days is indicated in patients with endocarditis (duration of treatment, 4 to 6 weeks) or *Staphylococcus aureus* bacteremia (2 to 3 weeks).[64]


A central venous catheter in place for ≥3 days and at least one of the following: suspected infection without another confirmed source, signs of sepsis, sepsis, septic shock, or exit-site infection
Catheter needed?
No
Remove catheter
Order two blood cultures
Continue evaluation for infection
Yes
Order two blood cultures
Catheter site infected?
Yes
Exit-Site Infection
Remove catheter
Insert new catheter at new site
Start empirical antibiotics if sepsis or septic shock is present
No
Sepsis or septic shock?
Yes
Start empirical antibiotics
Septic shock?
No
Yes
Source of infection other than catheter probable?
Yes
No
No
Change catheter over guide wire
Culture catheter tip
Remove catheter
Culture catheter tip
Insert new catheter at new site
Tip culture positive?
No
Catheter Infection Unlikely
Continue evaluation for other sources of infection
Yes
Blood cultures positive?
No
Yes
Catheter Colonization
Remove catheter and insert new catheter at new site (if not already done)
Antibiotics are not indicated
Catheter-Related Bloodstream Infection
Remove catheter and insert new catheter at new site (if not already done)
Antibiotics are indicated
Tailor antibiotics to the sensitivity of organisms
Treat for 10–14 days

is available and physicians have adequate training, the use of ultrasound guidance should be routinely considered for cases in which internal jugular venous catheterization will be attempted.

RECOGNITION OF ARTERIAL PUNCTURE AND PREVENTION OF AIR EMBOLISM

In a patient with normal blood pressure and normal arterial oxygen tension, arterial puncture is usually easy to identify by the pulsatile flow into the syringe and the bright-red color of the blood. However, in patients with profound hypotension or marked arterial desaturation, these findings may not be present. If there is any doubt as to whether the introducer needle is in the artery or the vein, an 18-gauge, single-lumen catheter (included in most kits) should be inserted over the wire and into the vessel. This step does not require the use of a dilator. This catheter can then be connected to a pressure transducer to confirm the presence of venous waveforms and venous pressure. Simultaneous samples for measurement of blood gases can then be drawn, one from the catheter and another from an artery. There should be a substantial difference in the oxygen tension if the catheter is located in a vein.

A spontaneously breathing patient generates negative intrathoracic pressure during inspiration. If a catheter is open to room air, this negative intrathoracic pressure can draw air into the vein, resulting in air embolism. Even small amounts of air can be fatal, especially if transmitted to the systemic circulation through an atrial or ventricular septal defect. To prevent this complication, catheter hubs should be occluded at all times, and the patient should be placed in Trendelenburg's position during insertion. If air embolism occurs, the patient should be placed in Trendelenburg's position with a left lateral decubitus tilt to prevent the movement of air into the right ventricular outflow tract. One hundred percent oxygen should be administered to speed the resorption of the air. If a catheter is located in the heart, aspiration of the air should be attempted.

PROPHYLACTIC ANTIBIOTICS

Most studies of the use of prophylactic antibiotics have demonstrated that this strategy is associated with reductions in the rate of catheter-related bloodstream infections.[40-42] However, this use of antibiotics is discouraged because of concern that it will encourage the emergence of antibiotic-resistant organisms.[43]

MAINTENANCE OF THE INSERTION SITE

OINTMENTS, SUBCUTANEOUS CUFFS, AND DRESSINGS

Application of antibiotic ointments (e.g., bacitracin, mupirocin, neomycin, and polymyxin) to catheter-insertion sites increases the rate of catheter colonization by fungi,[15] promotes the emergence of antibiotic-resistant bacteria,[16] and has not been shown to lower the rate of catheter-related bloodstream infections.[17] These ointments should not be used.[44] Likewise, the use of silver-impregnated subcutaneous cuffs has not been shown to reduce the incidence of catheter-related bloodstream infections and therefore is not recommended.[15,45,46] Because there are conflicting data on the optimal type of dressing (gauze vs. transparent material)[47,48] and the optimal frequency of dressing changes,[49,50] evidence-based recommendations cannot be made.

HUBS AND NEEDLELESS ACCESS DEVICES

Catheter hubs are a common source of contamination,[18] especially during prolonged catheterization.[51] The use of two types of antiseptic-containing hub has been shown to decrease the risk of catheter-related bloodstream infections.[52,53] In some hospitals, the introduction of needleless access devices has been linked to an increase in the rate of these infections.[54,55] In one instance, this increase was due to a high rate of noncompliance with the manufacturer's recommendations to change the end cap with each use and to change the device every three days.[54] In another, more frequent hub changes were required before the rate of catheter-related bloodstream infection returned to base line.[55]

CATHETER MAINTENANCE

Every catheter should be removed as soon as it is no longer needed, since the probability of catheter-related infections increases over time. The risks of catheter colonization and catheter-related bloodstream infection are low until the fifth to seventh days of catheterization, at which time the risks increase.[9,10,21] Multiple trials have tested strategies for reducing the risk of catheter-related infections, including scheduled, routine replacement of catheters by exchange over a guide wire and scheduled, routine replacement at a new site. However, none of these strategies have been shown to decrease the rate of catheter-related bloodstream infections.[19,20,56] In fact, scheduled, routine exchanges of catheters over a guide wire are associated with a trend toward an increased rate of catheter-related infections.[19] Furthermore, the more frequently a catheter is replaced with a new catheter at a new site, the more likely it is that the patient will have a mechanical complication during insertion.[19,27] A meta-analysis of 12 randomized trials of catheter-replacement strategies concluded that the data do not support either scheduled, routine exchange of catheters over a guide wire or scheduled, routine replacement at a new site.[19] Accordingly, central venous catheters should not be replaced on a scheduled basis.[44]

SUSPECTED CATHETER-RELATED BLOODSTREAM INFECTION

Even with optimal efforts to prevent infectious complications of central venous catheterization, catheter-associated infections will develop in some patients (Table 3). In any patient who has a central venous catheter, symptoms and signs of infection without another confirmed source should raise the concern that the catheter may be the source of the infection (Fig. 2). Once a catheter-associated infection is suspected, two samples of blood should be drawn for culture to evaluate the possibility of bacteremia. Two cultures of blood from peripheral sites should be evaluated because it is difficult to determine whether a positive culture of blood from a central venous catheter indicates contamination of the hub, catheter colonization, or a catheter-related bloodstream infection.[65,66] However, a negative culture from a catheter indicates that the presence of a catheter-related bloodstream infection is unlikely.[67]

The catheter site should be examined carefully. If there is any purulence or erythema, an exit-site infection is likely, and the catheter needs to be removed. If the patient has signs of either sepsis or septic shock, empirical antibiotic therapy should be begun to treat *Staphylococcus epidermidis* or *S. aureus* infections. Antibiotic therapy for gram-negative organisms should be added, especially if the patient is immunocompromised or has neutropenia or has other risk factors for infection with gram-negative organisms. The catheter should be changed over a guide wire.[56,62,63] This technique reduces the number of insertion-related complications and is safe, even in patients with sepsis, as long as antibiotic therapy has been initiated.[56,63] In patients who have septic shock and no other source of infection, the catheter should be removed and replaced with a new one at a new site.

If a culture of the catheter tip is positive, the patient has either catheter colonization or a catheter-related bloodstream infection, and a catheter that was replaced over a guide wire should be removed. If the catheter-tip culture is negative, then catheter colonization and catheter-related bloodstream infection are unlikely, and efforts should be made to identify another source of infection.

Supported in part by a Research Career Development Award from the Department of Veterans Affairs Health Services Research and Development Service (to Dr. Gould).

We are indebted to Drs. Deborah Cook and Stephen Ruoss for reviewing a previous version of the manuscript.

references

1. Raad I. Intravascular-catheter-related infections. Lancet 1998;351:893-8.
2. Pittet D, Tarara D, Wenzel RP. Nosocomial bloodstream infection in critically ill patients: excess length of stay, extra costs, and attributable mortality. JAMA 1994;271:1598-601.
3. Arnow PM, Quimosing EM, Beach M. Consequences of intravascular catheter sepsis. Clin Infect Dis 1993;16:778-84.
4. Richards MJ, Edwards JR, Culver DH, Gaynes RP. Nosocomial infections in medical intensive care units in the United States. Crit Care Med 1999;27:887-92.
5. Merrer J, De Jonghe B, Golliot F, et al. Complications of femoral and subclavian venous catheterization in critically ill patients: a randomized controlled trial. JAMA 2001;286:700-7.
6. Sznajder JI, Zveibil FR, Bitterman H, Weiner P, Bursztein S. Central vein catheterization: failure and complication rates by three percutaneous approaches. Arch Intern Med 1986;146:259-61.
7. Veenstra DL, Saint S, Saha S, Lumley T, Sullivan SD. Efficacy of antiseptic-impregnated central venous catheters in preventing catheter-related bloodstream infection: a meta-analysis. JAMA 1999;281:261-7.
8. Mansfield PF, Hohn DC, Fornage BD, Gregurich MA, Ota DM. Complications and failures of subclavian-vein catheterization. N Engl J Med 1994;331:1735-8.
9. Raad I, Darouiche R, Dupuis J, et al. Central venous catheters coated with minocycline and rifampin for the prevention of catheter-related colonization and bloodstream infections: a randomized, double-blind trial. Ann Intern Med 1997;127:267-74.
10. Maki DG, Stolz SM, Wheeler S, Mermel LA. Prevention of central venous catheter-related bloodstream infection by use of an antiseptic-impregnated catheter: a randomized, controlled trial. Ann Intern Med 1997;127:257-66.
11. Veenstra DL, Saint S, Sullivan SD. Cost-effectiveness of antiseptic-impregnated central venous catheters for the prevention of catheter-related bloodstream infection. JAMA 1999;282:554-60.
12. Heard SO, Wagle M, Vijayakumar E, et al. Influence of triple-lumen central venous catheters coated with chlorhexidine and silver sulfadiazine on the incidence of catheter-related bacteremia. Arch Intern Med 1998;158:81-7.
13. McKinley S, Mackenzie A, Finfer S, Ward R, Penfold J. Incidence and predictors of central venous catheter related infection in intensive care patients. Anaesth Intensive Care 1999;27:164-9.
14. Raad II, Hohn DC, Gilbreath BJ, et al. Prevention of central venous catheter-related

infections by using maximal sterile barrier precautions during insertion. Infect Control Hosp Epidemiol 1994;15:231-8.
15. Flowers RH III, Schwenzer KJ, Kopel RF, Fisch MJ, Tucker SI, Farr BM. Efficacy of an attachable subcutaneous cuff for the prevention of intravascular catheter-related infection: a randomized, controlled trial. JAMA 1989;261:878-83.
16. Zakrzewska-Bode A, Muytjens HL, Liem KD, Hoogkamp-Korstanje JA. Mupirocin resistance in coagulase-negative staphylococci, after topical prophylaxis for the reduction of colonization of central venous catheters. J Hosp Infect 1995;31:189-93.
17. Maki DG, Band JD. A comparative study of polyantibiotic and iodophor ointments in prevention of vascular catheter-related infection. Am J Med 1981;70:739-44.
18. Salzman MB, Isenberg HD, Shapiro JF, Lipsitz PJ, Rubin LG. A prospective study of the catheter hub as the portal of entry for microorganisms causing catheter-related sepsis in neonates. J Infect Dis 1993;167:487-90.
19. Cook D, Randolph A, Kernerman P, et al. Central venous catheter replacement strategies: a systematic review of the literature. Crit Care Med 1997;25:1417-24.
20. Bonawitz SC, Hammell EJ, Kirkpatrick JR. Prevention of central venous catheter sepsis: a prospective randomized trial. Am Surg 1991;57:618-23.
21. Collin GR. Decreasing catheter colonization through the use of an antiseptic-impregnated catheter: a continuous quality improvement project. Chest 1999;115:1632-40.
22. Martin C, Eon B, Auffray JP, Saux P, Gouin F. Axillary or internal jugular central venous catheterization. Crit Care Med 1990; 18:400-2.
23. Durbec O, Viviand X, Potie F, Vialet R, Albanese J, Martin C. A prospective evaluation of the use of femoral venous catheters in critically ill adults. Crit Care Med 1997;25: 1986-9.
24. Timsit JF, Bruneel F, Cheval C, et al. Use of tunneled femoral catheters to prevent catheter-related infection: a randomized, controlled trial. Ann Intern Med 1999;130: 729-35.
25. Teichgraber UK, Benter T, Gebel M, Manns MP. A sonographically guided technique for central venous access. AJR Am J Roentgenol 1997;169:731-3.
26. Randolph AG, Cook DJ, Gonzales CA, Pribble CG. Ultrasound guidance for placement of central venous catheters: a meta-analysis of the literature. Crit Care Med 1996;24: 2053-8.
27. Cobb DK, High KP, Sawyer RG, et al. A controlled trial of scheduled replacement of central venous and pulmonary-artery catheters. N Engl J Med 1992;327:1062-8.
28. Timsit JF, Farkas JC, Boyer JM, et al. Central vein catheter-related thrombosis in intensive care patients: incidence, risk factors, and relationship with catheter-related sepsis. Chest 1998;114:207-13.
29. Darouiche RO, Raad II, Heard SO, et al. A comparison of two antimicrobial-impregnated central venous catheters. N Engl J Med 1999;340:1-8.
30. Ma TY, Yoshinaka R, Banaag A, Johnson B, Davis S, Berman SM. Total parenteral nutrition via multilumen catheters does not increase the risk of catheter-related sepsis: a randomized, prospective study. Clin Infect Dis 1998;27:500-3.
31. Farkas JC, Liu N, Bleriot JP, Chevret S, Goldstein FW, Carlet J. Single- versus triple-lumen central catheter-related sepsis: a prospective randomized study in a critically ill population. Am J Med 1992;93:277-82.
32. Clark-Christoff N, Watters VA, Sparks W, Snyder P, Grant JP. Use of triple-lumen subclavian catheters for administration of total parenteral nutrition. JPEN J Parenter Enteral Nutr 1992;16:403-7.
33. Venus B, Satish P. Vascular cannulation. In: Civetta JM, Taylor RW, Kirby RR, eds. Critical care. 3rd ed. Philadelphia: Lippincott-Raven, 1997:521-44.
34. Hirsch DR, Ingenito EP, Goldhaber SZ. Prevalence of deep venous thrombosis among patients in medical intensive care. JAMA 1995;274:335-7.
35. Maki DG, Ringer M, Alvarado CJ. Prospective randomised trial of povidone-iodine, alcohol, and chlorhexidine for prevention of infection associated with central venous and arterial catheters. Lancet 1991;338:339-43.
36. Mimoz O, Pieroni L, Lawrence C, et al. Prospective, randomized trial of two antiseptic solutions for prevention of central venous or arterial catheter colonization and infection in intensive care unit patients. Crit Care Med 1996;24:1818-23.
37. Fares LG II, Block PH, Feldman SD. Improved house staff results with subclavian cannulation. Am Surg 1986;52:108-11.
38. Lefrant JY, Cuvillon P, Benezet JF, et al. Pulsed Doppler ultrasonography guidance for catheterization of the subclavian vein: a randomized study. Anesthesiology 1998; 88:1195-201.
39. Bold RJ, Winchester DJ, Madary AR, Gregurich MA, Mansfield PF. Prospective, randomized trial of Doppler-assisted subclavian vein catheterization. Arch Surg 1998;133: 1089-93.
40. Raad II, Hachem RY, Abi-Said D, et al. A prospective crossover randomized trial of novobiocin and rifampin prophylaxis for the prevention of intravascular catheter infections in cancer patients treated with interleukin-2. Cancer 1998;82:403-11.
41. Henrickson KJ, Axtell RA, Hoover SM, et al. Prevention of central venous catheter-related infections and thrombotic events in immunocompromised children by the use of vancomycin/ciprofloxacin/heparin flush solution: a randomized, multicenter, double-blind trial. J Clin Oncol 2000;18:1269-78.
42. Bock SN, Lee RE, Fisher B, et al. A prospective randomized trial evaluating prophylactic antibiotics to prevent triple-lumen catheter-related sepsis in patients treated with immunotherapy. J Clin Oncol 1990;8:161-9.
43. Recommendations for preventing the spread of vancomycin resistance: recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC). MMWR Morb Mortal Wkly Rep 1995;44 (RR-12):1-13.
44. Pearson ML. Guideline for prevention of intravascular device-related infections. Infect Control Hosp Epidemiol 1996;17:438-73.
45. Maki DG, Cobb L, Garman JK, Shapiro JM, Ringer M, Helgerson RB. An attachable silver-impregnated cuff for prevention of infection with central venous catheters: a prospective randomized multicenter trial. Am J Med 1988;85:307-14.
46. Smith HO, DeVictoria CL, Garfinkel D, et al. A prospective randomized comparison of an attached silver-impregnated cuff to prevent central venous catheter-associated infection. Gynecol Oncol 1995;58:92-100.
47. Conly JM, Grieves K, Peters B. A prospective, randomized study comparing transparent and dry gauze dressings for central venous catheters. J Infect Dis 1989;159:310-9.
48. Maki DG, Stolz SS, Wheeler S, Mermel LA. A prospective, randomized trial of gauze and two polyurethane dressings for site care of pulmonary artery catheters: implications for catheter management. Crit Care Med 1994;22:1729-37.
49. Laura R, Degl'Innocenti M, Mocali M, et al. Comparison of two different time interval protocols for central venous catheter dressing in bone marrow transplant patients: results of a randomized, multicenter study. Haematologica 2000;85:275-9.
50. Engervall P, Ringertz S, Hagman E, Skogman K, Bjorkholm M. Change of central venous catheter dressings twice a week is superior to once a week in patients with haematological malignancies. J Hosp Infect 1995;29:275-86.
51. Raad I, Costerton W, Sabharwal U, Sacilowski M, Anaissie E, Bodey GP. Ultrastructural analysis of indwelling vascular catheters: a quantitative relationship between luminal colonization and duration of placement. J Infect Dis 1993;168:400-7.
52. Segura M, Alvarez-Lerma F, Tellado JM, et al. A clinical trial on the prevention of catheter-related sepsis using a new hub model. Ann Surg 1996;223:363-9.
53. Halpin DP, O'Byrne P, McEntee G, Hennessy TP, Stephens RB. Effect of a betadine connection shield on central venous catheter sepsis. Nutrition 1991;7:33-4.
54. Cookson ST, Ihrig M, O'Mara EM, et al. Increased bloodstream infection rates in surgical patients associated with variation from recommended use and care following implementation of a needleless device. Infect Control Hosp Epidemiol 1998;19:23-7.
55. McDonald LC, Banerjee SN, Jarvis WR. Line-associated bloodstream infections in pediatric intensive-care-unit patients associated with a needleless device and intermittent intravenous therapy. Infect Control Hosp Epidemiol 1998;19:772-7.
56. Martinez E, Mensa J, Rovira M, et al. Cen-

tral venous catheter exchange by guidewire for treatment of catheter-related bacteraemia in patients undergoing BMT or intensive chemotherapy. Bone Marrow Transplant 1999;23:41-4.
57. Maki DG, Weise CE, Sarafin HW. A semiquantitative culture method for identifying intravenous-catheter-related infection. N Engl J Med 1977;296:1305-9.
58. Sherertz RJ, Raad II, Belani A, et al. Three-year experience with sonicated vascular catheter cultures in a clinical microbiology laboratory. J Clin Microbiol 1990;28:76-82.
59. Sherertz RJ, Heard SO, Raad II. Diagnosis of triple-lumen catheter infection: comparison of roll plate, sonication, and flushing methodologies. J Clin Microbiol 1997;35:641-6.
60. Raad II, Sabbagh MF, Rand KH, Sherertz RJ. Quantitative tip culture methods and the diagnosis of central venous catheter-related infections. Diagn Microbiol Infect Dis 1992;15:13-20. [Erratum, Diagn Microbiol Infect Dis 1992;15:384.]
61. Abraham E, Matthay MA, Dinarello CA, et al. Consensus conference definitions for sepsis, septic shock, acute lung injury, and acute respiratory distress syndrome: time for a reevaluation. Crit Care Med 2000;28:232-5.
62. Eyer S, Brummitt C, Crossley K, Siegel R, Cerra F. Catheter-related sepsis: prospective, randomized study of three methods of long-term catheter maintenance. Crit Care Med 1990;18:1073-9.
63. Michel LA, Bradpiece HA, Randour P, Pouthier F. Safety of central venous catheter change over guidewire for suspected catheter-related sepsis: a prospective randomized trial. Int Surg 1988;73:180-6.
64. Jernigan JA, Farr BM. Short-course therapy of catheter-related Staphylococcus aureus bacteremia: a meta-analysis. Ann Intern Med 1993;119:304-11.
65. Bryant JK, Strand CL. Reliability of blood cultures collected from intravascular catheter versus venipuncture. Am J Clin Pathol 1987;88:113-6.
66. Washington JA II, Ilstrup DM. Blood cultures: issues and controversies. Rev Infect Dis 1986;8:792-802.
67. DesJardin JA, Falagas ME, Ruthazer R, et al. Clinical utility of blood cultures drawn from indwelling central venous catheters in hospitalized patients with cancer. Ann Intern Med 1999;131:641-7.