

Guidelines for the Prevention of Intravascular Catheter-Related Infections

Naomi P. O'Grady, MD*; Mary Alexander, BS‡; E. Patchen Dellinger, MD§;
Julie L. Gerberding, MD, MPH||; Stephen O. Heard, MD¶; Dennis G. Maki, MD#; Henry Masur, MD*;
Rita D. McCormick, RN**; Leonard A. Mermel, DO‡‡; Michele L. Pearson, MD§§; Issam I. Raad, MD|||;
Adrienne Randolph, MD, MSc¶¶; and Robert A. Weinstein, MD###

ABSTRACT. These guidelines have been developed for practitioners who insert catheters and for persons responsible for surveillance and control of infections in hospital, outpatient, and home health-care settings. This report was prepared by a working group comprising members from professional organizations representing the disciplines of critical care medicine, infectious diseases, health-care infection control, surgery, anesthesiology, interventional radiology, pulmonary medicine, pediatric medicine, and nursing. The working group was led by the Society of Critical Care Medicine (SCCM), in collaboration with the Infectious Disease Society of America (IDSA), Society for Healthcare Epidemiology of America (SHEA), Surgical Infection Society (SIS), American College of Chest Physicians (ACCP), American Thoracic Society (ATS), American Society of Critical Care Anesthesiologists (ASCCA), Association for Professionals in Infection Control and Epidemiology (APIC), Infusion Nurses Society (INS), Oncology Nursing Society (ONS), Society of Cardiovascular and Interventional Radiology (SCVIR), American Academy of Pediatrics (AAP), and the Healthcare Infection Control Practices Advisory Committee (HICPAC) of the Centers for Disease Control and Prevention (CDC) and is intended to replace the *Guideline for Prevention of Intravascular Device-Related Infections* published in 1996. These guidelines are intended to provide evidence-based recommendations for preventing catheter-related infections. Major areas of emphasis include 1) educating and training health-care providers who insert and maintain catheters; 2) using maximal sterile barrier precautions during central venous catheter insertion; 3) using a 2% chlorhexidine preparation for skin antisepsis; 4) avoiding routine replacement of central venous catheters as a strategy to prevent infection; and 5) using antiseptic/antibiotic impregnated short-term central venous catheters if the rate of infection is high despite adherence to other strategies

(ie, education and training, maximal sterile barrier precautions, and 2% chlorhexidine for skin antisepsis). These guidelines also identify performance indicators that can be used locally by health-care institutions or organizations to monitor their success in implementing these evidence-based recommendations. *Pediatrics* 2002; 110(5). URL: <http://www.pediatrics.org/cgi/content/full/110/5/e51>; *catheter-related bloodstream infections, intensive care unit, central venous catheter, peripherally inserted central catheter, guidelines.*

ABBREVIATIONS. CRBSI, catheter-related bloodstream infections; HICPAC, Healthcare Infection Control Practices Advisory Committee; CDC, Centers for Disease Control and Prevention; ICU, intensive care unit; BSI, bloodstream infection; CVC, central venous catheter; PICC, peripherally inserted central catheter; NNIS, National Nosocomial Infection Surveillance; RR, relative risk; CI, confidence interval; IV, intravenous; FDA, US Food and Drug Administration; VRE, vancomycin-resistant enterococcus; VCH, vancomycin/ciprofloxacin/heparin; VH, vancomycin/heparin.

INTRODUCTION

This report provides health-care practitioners with background information and specific recommendations to reduce the incidence of intravascular catheter-related bloodstream infections (CRBSI). These guidelines replace the *Guideline for Prevention of Intravascular Device-Related Infections*, which was published in 1996.¹

The *Guidelines for the Prevention of Intravascular Catheter-Related Infections* have been developed for practitioners who insert catheters and for persons who are responsible for surveillance and control of infections in hospital, outpatient, and home health-care settings. This report was prepared by a working group composed of professionals representing the disciplines of critical care medicine, infectious diseases, health-care infection control, surgery, anesthesiology, interventional radiology, pulmonary medicine, pediatrics, and nursing. The working group was led by the Society of Critical Care Medicine (SCCM), in collaboration with Infectious Disease Society of America (IDSA), Society for Healthcare Epidemiology of America (SHEA), Surgical Infection Society (SIS), American College of Chest Physicians (ACCP), American Thoracic Society (ATS), American Society of Critical Care Anesthesiologists (ASCCA), Association for Professionals in Infection Control and Epidemiology (APIC), Infusion Nurses Society (INS), Oncology Nursing Society (ONS), Society of Cardiovascular and Interventional Radiology

From the *National Institutes of Health, Bethesda, Maryland; ‡Infusion Nurses Society, Cambridge, Massachusetts; §University of Washington, Seattle, Washington; ||Office of the Director, CDC, Atlanta, Georgia; ¶University of Massachusetts Medical School, Worcester, Massachusetts; #University of Wisconsin Medical School, Madison, Wisconsin; **University of Wisconsin Hospital and Clinics, Madison, Wisconsin; ‡‡Rhode Island Hospital and Brown University School of Medicine, Providence, Rhode Island; §§Division of Healthcare Quality Promotion, National Center for Infectious Diseases Centers for Disease Control and Prevention, Atlanta, Georgia; |||M. D. Anderson Cancer Center, Houston, Texas; ¶¶The Children's Hospital, Boston, Massachusetts; and ###Cook County Hospital and Rush Medical College, Chicago, Illinois.

Received for publication; Mar 8 2002; accepted Mar 8, 2002.

Address correspondence to Naomi P. O'Grady, MD, National Institutes of Health, Department of Critical Care Medicine, 9000 Rockville Pike, Bldg 10, Rm 7D43, Bethesda, MD 20892.

PEDIATRICS (ISSN 0031 4005). Copyright © 2002 by the American Academy of Pediatrics.

APPENDIX A

Examples of Clinical Definitions for Catheter-Related Infections Localized Catheter Colonization

Significant growth of a microorganism (>15 CFU) from the catheter tip, subcutaneous segment of the catheter, or catheter hub

Exit Site Infection

Erythema or induration within 2 cm of the catheter exit site, in the absence of concomitant BSI and without concomitant purulence

Clinical Exit Site Infection (or Tunnel Infection)

Tenderness, erythema, or site induration >2 cm from the catheter site along the subcutaneous tract of a tunneled (eg, Hickman, Broviac) catheter, in the absence of concomitant BSI

Pocket Infection

Purulent fluid in the subcutaneous pocket of a totally implanted intravascular catheter that might or might not be associated with spontaneous rupture and drainage or necrosis of the overlying skin, in the absence of concomitant BSI

Infusate-Related BSI

Concordant growth of the same organism from the infusate and blood cultures (preferably percutaneously drawn) with no other identifiable source of infection

CRBSI

Bacteremia/fungemia in a patient with an intravascular catheter with at least 1 positive blood culture obtained from a peripheral vein, clinical manifestations of infections (ie, fever, chills, and/or hypotension), and no apparent source for the BSI except the catheter. One of the following should be present: a positive semiquantitative (>15 CFU/catheter segment) or quantitative (>103 CFU/catheter segment catheter) culture whereby the same organism (species and antibiogram) is isolated from the catheter segment and peripheral blood; simultaneous quantitative blood cultures with a >5:1 ratio CVC versus peripheral; differential period of CVC culture versus peripheral blood culture positivity of >2 hours.

Surveillance Definitions for Primary BSIs, NNIS System

Laboratory-Confirmed BSI

Should meet at least 1 of the following criteria:

Criterion 1: Patient has a recognized pathogen cultured from 1 or more blood cultures, and the pathogen cultured from the blood is not related to an infection at another site.

Criterion 2: Patient has at least 1 of the following signs or symptoms: fever (>100.4°F [>38°C]), chills, or hypotension, and at least 1 of the following:

1. Common skin contaminant (eg, diphtheroids, *Bacillus* species, *Propionibacterium* species, coagulase-negative staphylococci, micrococci) cultured from 2 or more blood cultures drawn on separate occasions
2. Common skin contaminant (eg, diphtheroids, *Bacillus* species, *Propionibacterium* species, coagulase-negative staphylococci, micrococci) cultured from at least 1 blood culture from a patient with an intravenous line, and the physician institutes appropriate antimicrobial therapy
3. Positive antigen test on blood (eg, *Hemophilus influenzae*, *Streptococcus pneumoniae*, *Neisseria meningitidis*, group B streptococcus) **and signs and symptoms with positive laboratory results are not related to an infection at another site.**

Criterion 3: Patient aged <1 year has at least 1 of the following signs or symptoms: fever (>100.4°F [>38°C]), hypo-

thermia (<98.6°F [<37°C]), apnea, or bradycardia, and at least 1 of the following:

1. Common skin contaminant (eg, diphtheroids, *Bacillus* species, *Propionibacterium* species, coagulase-negative staphylococci, micrococci) cultured from 2 or more blood cultures drawn on separate occasions
2. Common skin contaminant (eg, diphtheroids, *Bacillus* species, *Propionibacterium* species, coagulase-negative staphylococci, micrococci) cultured from at least 1 blood culture from a patient with an intravenous line, and the physician institutes appropriate antimicrobial therapy
3. Positive antigen test on blood (eg, *H influenzae*, *S pneumoniae*, *N meningitidis*, group B streptococcus) **and signs and symptoms with positive laboratory results are not related to an infection at another site.**

Clinical Sepsis

Should meet at least 1 of the following criteria:

Criterion 1: Patient has at least 1 of the following clinical signs with no other recognized cause: fever (>100.4°F [>38°C]), hypotension (systolic pressure <90 mmHg), or oliguria (<20 mL/h), and blood culture not done or no organisms or antigen detected in blood and no apparent infection at another site, and physician institutes treatment for sepsis.

Criterion 2: Patient aged <1 year has at least 1 of the following clinical signs or symptoms with no other recognized cause: fever (>100.4°F [>38°C]), hypothermia (<98.6°F [<37°C]), apnea, or bradycardia, and blood culture not done or no organisms or antigen detected in blood and no apparent infection at another site, and physician institutes treatment for sepsis.

Catheter-Associated BSI

Defined by the following:

- Vascular access device that terminates at or close to the heart or 1 of the great vessels. An umbilical artery or vein catheter is considered a central line.
- BSI is considered to be associated with a central line if the line was in use during the 48-hour period before development of the BSI. If the time interval between onset of infection and device use is >48 hours, then there should be compelling evidence that the infection is related to the central line.

Arterial or Venous Infection

Included are arteriovenous graft, shunt, fistula, or intravenous cannulation. Should meet at least 1 of the following criteria:

Criterion 1: Patient has organisms cultured from arteries or veins removed during a surgical operation and blood culture not done or no organisms cultured from blood.

Criterion 2: Patient has evidence of arterial or venous infection seen during a surgical operation or histopathologic examination.

Criterion 3: Patient has at least 1 of the following signs or symptoms with no other recognized cause: fever (>100.4°F [>38°C]), pain, erythema, or heat at involved vascular site and >15 CFUs cultured from an intravascular cannula tip using a semiquantitative culture method and blood culture not done or no organisms cultured from blood.

Criterion 4: Patient has purulent drainage at the involved vascular site and blood culture not done or no organisms cultured from blood.

Criterion 5: Patient aged <1 year has at least 1 of the following signs or symptoms with no other recognized cause: fever (>100.4°F [>38°C]), hypothermia (<98.6°F [<37°C]), apnea, bradycardia, lethargy, or pain, erythema or heat at involved vascular site and >15 colonies cultured from intravascular cannula tip using semiquantitative method and blood culture not done or no organisms cultured from blood.

(SCVIR), American Academy of Pediatrics (AAP), and the Healthcare Infection Control Practices Advisory Committee (HICPAC) of the Centers for Disease Control and Prevention (CDC). The recommendations presented in this report reflect consensus of HICPAC and other professional organizations.

INTRAVASCULAR CATHETER-RELATED INFECTIONS IN ADULT AND PEDIATRIC PATIENTS: AN OVERVIEW

Background

Intravascular catheters are indispensable in modern-day medical practice, particularly in intensive care units (ICUs). Although such catheters provide necessary vascular access, their use puts patients at risk for local and systemic infectious complications, including local site infection, CRBSI, septic thrombophlebitis, endocarditis, and other metastatic infections (eg, lung abscess, brain abscess, osteomyelitis, and endophthalmitis).

Health-care institutions purchase millions of intravascular catheters each year. The incidence of CRBSI varies considerably by type of catheter, frequency of catheter manipulation, and patient-related factors (eg, underlying disease and acuity of illness). Peripheral venous catheters are the devices most frequently used for vascular access. Although the incidence of local or bloodstream infections (BSIs) associated with peripheral venous catheters is usually low, serious infectious complications produce considerable annual morbidity because of the frequency with which such catheters are used. However, the majority of serious catheter-related infections are associated with central venous catheters (CVCs), especially those that are placed in patients in ICUs. In the ICU setting, the incidence of infection is often higher than in the less acute in-patient or ambulatory setting. In the ICU, central venous access might be needed for extended periods of time; patients can be colonized with hospital-acquired organisms; and the catheter can be manipulated multiple times per day for the administration of fluids, drugs, and blood products. Moreover, some catheters can be inserted in urgent situations, during which optimal attention to aseptic technique might not be feasible. Certain catheters (eg, pulmonary artery catheters and peripheral arterial catheters) can be accessed multiple times per day for hemodynamic measurements or to obtain samples for laboratory analysis, augmenting the potential for contamination and subsequent clinical infection.

The magnitude of the potential for CVCs to cause morbidity and mortality resulting from infectious complications has been estimated in several studies.² In the United States, 15 million CVC days (ie, the total number of days of exposure to CVCs by all patients in the selected population during the selected time period) occur in ICUs each year.² If the average rate of CVC-associated BSIs is 5.3 per 1,000 catheter days in the ICU,³ approximately 80,000 CVC-associated BSIs occur in ICUs each year in the United States. The attributable mortality for these BSIs has ranged from no increase in mortality in

studies that controlled for severity of illness,^{4–6} to 35% increase in mortality in prospective studies that did not use this control.^{7,8} Thus, the attributable mortality remains unclear. The attributable cost per infection is an estimated \$34,508–\$56,000,^{5,9} and the annual cost of caring for patients with CVC-associated BSIs ranges from \$296 million to \$2.3 billion.¹⁰

A total of 250,000 cases of CVC-associated BSIs have been estimated to occur annually if entire hospitals are assessed rather than ICUs exclusively.¹¹ In this case, attributable mortality is an estimated 12%–25% for each infection, and the marginal cost to the health-care system is \$25,000 per episode.¹¹

Therefore, by several analyses, the cost of CVC-associated BSI is substantial, both in terms of morbidity and in terms of financial resources expended. To improve patient outcome and reduce health-care costs, strategies should be implemented to reduce the incidence of these infections. This effort should be multidisciplinary, involving health-care professionals who insert and maintain intravascular catheters, health-care managers who allocate resources, and patients who are capable of assisting in the care of their catheters. Although several individual strategies have been studied and shown to be effective in reducing CRBSI, studies using multiple strategies have not been conducted. Thus, it is not known whether implementing multiple strategies will have an additive effect in reducing CRBSI, but it is logical to use multiple strategies concomitantly.

Terminology and Estimates of Risk

The terminology used to identify different types of catheters is confusing, because many clinicians and researchers use different aspects of the catheter for informal reference. A catheter can be designated by the type of vessel it occupies (eg, peripheral venous, central venous, or arterial); its intended life span (eg, temporary or short-term versus permanent or long-term); its site of insertion (eg, subclavian, femoral, internal jugular, peripheral, and peripherally inserted central catheter [PICC]); its pathway from skin to vessel (eg, tunneled versus nontunneled); its physical length (eg, long versus short); or some special characteristic of the catheter (eg, presence or absence of a cuff, impregnation with heparin, antibiotics or antiseptics, and the number of lumens). To accurately define a specific type of catheter, all of these aspects should be described (Table 1).

The rate of all catheter-related infections (including local infections and systemic infections) is difficult to determine. Although CRBSI is an ideal parameter because it represents the most serious form of catheter-related infection, the rate of such infection depends on how CRBSI is defined.

Health-care professionals should recognize the difference between surveillance definitions and clinical definitions. The surveillance definitions for catheter-associated BSI includes all BSIs that occur in patients with CVCs, when other sites of infection have been excluded (Appendix A). That is, the surveillance definition overestimates the true incidence of CRBSI because not all BSIs originate from a catheter. Some bacteremias are secondary BSIs from undocumented

TABLE 1. Catheters Used for Venous and Arterial Access

Catheter Type	Entry Site	Length	Comments
Peripheral venous catheters (short)	Usually inserted in veins of forearm or hand	<3 in	Phlebitis with prolonged use; rarely associated with bloodstream infection
Peripheral arterial catheters	Usually inserted in radial artery; can be placed in femoral, axillary, brachial, posterior tibial arteries	<3 in	Low infection risk; rarely associated with bloodstream infection
Midline catheters	Inserted via the antecubital fossa into the proximal basilic or cephalic veins; does not enter central veins	3–8 in	Anaphylactoid reactions have been reported with catheters made of elastomeric hydrogel; lower rates of phlebitis than short peripheral catheters
Nontunneled CVCs	Percutaneously inserted into central veins (subclavian, internal jugular, or femoral)	8 cm or longer, depending on patient size	Account for majority of CRBSI
Pulmonary artery catheters	Inserted through a Teflon introducer in a central vein (subclavian, internal jugular, or femoral)	30 cm or longer, depending on patient size	Usually heparin bonded; similar rates of bloodstream infection as CVC; subclavian site preferred to reduce infection risk
PICCs	Inserted into basilic, cephalic, or brachial veins and enter the superior vena cava	20 cm or longer, depending on patient size	Lower rate of infection than nontunneled CVCs
Tunneled CVCs	Implanted into subclavian, internal jugular, or femoral veins	8 cm or longer, depending on patient size	Cuff inhibits migration of organisms into catheter tract, lower rate of infection than nontunneled CVC
Totally implantable	Tunneled beneath skin and have devices subcutaneous port accessed with a needle; implanted in subclavian or internal jugular vein	8 cm or longer, depending on patient size	Lowest risk for CRBSI; improved patient self-image; no need for local catheter site care; surgery required for catheter removal
Umbilical catheters	Inserted into either umbilical vein or umbilical artery	6 cm or less, depending on patient size	Risk for CRBSI similar to catheters placed in umbilical vein versus artery

sources (eg, postoperative surgical sites, intra-abdominal infections, and hospital-associated pneumonia or urinary tract infections). Thus, surveillance definitions are really definitions for catheter-associated BSIs. A more rigorous definition might include only those BSIs for which other sources were excluded by careful examination of the patient record, and where a culture of the catheter tip demonstrated substantial colonies of an organism identical to those found in the bloodstream. Such a clinical definition would focus on catheter-related BSIs. Therefore, to accurately compare a health-care facility's infection rate to published data, comparable definitions also should be used.

CDC and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) recommend that the rate of catheter-associated BSIs be expressed as the number of catheter associated BSIs per 1,000 CVC days.^{12,13} This parameter is more useful than the rate expressed as the number of catheter-associated infections per 100 catheters (or percentage of catheters studied), because it accounts for BSIs over time and therefore adjusts risk for the number of days the catheter is in use.

Epidemiology and Microbiology

Since 1970, CDC's National Nosocomial Infection Surveillance System (NNIS) has been collecting data on the incidence and etiologies of hospital-acquired infections, including CVC-associated BSIs in a group of nearly 300 US hospitals. The majority of hospital-acquired BSIs are associated with the use of a CVC, with BSI rates being substantially higher among patients with CVCs than among those without CVCs. Rates of CVC-associated BSI vary considerably by

hospital size, hospital service/unit, and type of CVC. During 1992–2001, NNIS hospitals reported ICU rates of CVC-associated BSI ranging from 2.9 (in a cardiothoracic ICU) to 11.3 (in a neonatal nursery for infants weighing <1,000 g) BSIs per 1,000 CVC days (Table 2).¹⁴

The relative risk (RR) of catheter-associated BSI also has been assessed in a meta-analysis of 223 prospective studies of adult patients.¹¹ RR of infection was best determined by analyzing rates of infection both by BSIs per 100 catheters and BSIs per 1,000 catheter days. These rates, and the NNIS-derived data, can be used as benchmarks by individual hos-

TABLE 2. Pooled Means of the Distribution of CVC-Associated Bloodstream Infection Rates in Hospitals That Report to the NNIS System, January 1992 to June 2001

Type of ICU	Number of ICUs	Catheter Days	Pooled Mean/1000 Catheter Days
Coronary	102	252 325	4.5
Cardiothoracic	64	419 674	2.9
Medical	135	671 632	5.9
Medical/surgical			
Major teaching	123	579 704	5.3
All others	180	863 757	3.8
Neurosurgical	47	123 780	4.7
Nursery, high risk			
≤1000 g	138	438 261	11.3
1001–1500 g	136	213 351	6.9
1501–2500 g	132	163 697	4.0
>2500 g	133	231 573	3.8
Pediatric	74	291 831	7.6
Surgical	153	900 948	5.3
Trauma	25	116 709	7.9
Respiratory	7	21 265	3.4

Issued August 2001.^{290,291}

pitals to estimate how their rates compare with other institutions. Rates are influenced by patient-related parameters, such as severity of illness and type of illness (eg, third-degree burns versus postcardiac surgery), and by catheter-related parameters, such as the condition under which the catheter was placed (eg, elective versus urgent) and catheter type (eg, tunneled versus nontunneled or subclavian versus jugular).

Types of organisms that most commonly cause hospital-acquired BSIs change over time. During 1986–1989, coagulase-negative staphylococci, followed by *Staphylococcus aureus*, were the most frequently reported causes of BSIs, accounting for 27% and 16% of BSIs, respectively (Table 3).¹⁵ Pooled data from 1992 through 1999 indicate that coagulase-negative staphylococci, followed by enterococci, are now the most frequently isolated causes of hospital-acquired BSIs.¹² Coagulase-negative staphylococci account for 37%¹² and *S aureus* account for 12.6% of reported hospital-acquired BSIs.¹² Also notable was the susceptibility pattern of *S aureus* isolates. In 1999, for the first time since NNIS has been reporting susceptibilities, >50% of all *S aureus* isolates from ICUs were resistant to oxacillin.¹²

In 1999, enterococci accounted for 13.5% of BSIs, an increase from 8% reported to NNIS during 1986–1989. The percentage of enterococcal ICU isolates resistant to vancomycin also is increasing, escalating from 0.5% in 1989 to 25.9% in 1999.¹²

Candida spp caused 8% of hospital-acquired BSIs reported to NNIS during 1986–1989,^{15,16} and during 1992–1999.^{12,17,18} Resistance of *Candida* spp to commonly used antifungal agents is increasing. Although NNIS has not reported the percentage of BSIs caused by non-*albicans* species or fluconazole susceptibility data, other epidemiologic and clinical data document that fluconazole resistance is an increasingly relevant consideration when designing empiric therapeutic regimens for CRBSIs caused by yeast. Data from the Surveillance and Control of Pathogens of Epidemiologic Importance (SCOPE) Program documented that 10% of *C albicans* bloodstream isolates from hospitalized patients were resistant to fluconazole.¹⁷ Additionally, 48% of *Candida* BSIs were caused by non-*albicans* species, including *C glabrata* and *C krusei*, which are more likely than *C albicans* to demonstrate resistance to fluconazole and itraconazole.^{18,19}

Gram-negative bacilli accounted for 19% of catheter-associated BSIs during 1986–1989¹⁵ compared with 14% of catheter-associated BSIs during 1992–1999.¹² An increasing percentage of ICU-related isolates are caused by *Enterobacteriaceae* that produce extended-spectrum β -lactamases (ESBLs), particularly *Klebsiella pneumoniae*.²⁰ Such organisms not only are resistant to extended-spectrum cephalosporins, but also to frequently used, broad spectrum antimicrobial agents.

ter-associated BSIs during 1986–1989¹⁵ compared with 14% of catheter-associated BSIs during 1992–1999.¹² An increasing percentage of ICU-related isolates are caused by *Enterobacteriaceae* that produce extended-spectrum β -lactamases (ESBLs), particularly *Klebsiella pneumoniae*.²⁰ Such organisms not only are resistant to extended-spectrum cephalosporins, but also to frequently used, broad spectrum antimicrobial agents.

Pathogenesis

Migration of skin organisms at the insertion site into the cutaneous catheter tract with colonization of the catheter tip is the most common route of infection for peripherally inserted, short-term catheters.^{21,22} Contamination of the catheter hub contributes substantially to intraluminal colonization of long-term catheters.^{23–25} Occasionally, catheters might become hematogenously seeded from another focus of infection. Rarely, infusate contamination leads to CRBSI.²⁶

Important pathogenic determinants of catheter-related infection are 1) the material of which the device is made and 2) the intrinsic virulence factors of the infecting organism. In vitro studies demonstrate that catheters made of polyvinyl chloride or polyethylene are likely less resistant to the adherence of microorganisms than are catheters made of Teflon, silicone elastomer, or polyurethane.^{27,28} Therefore, the majority of catheters sold in the United States are no longer made of polyvinyl chloride or polyethylene. Some catheter materials also have surface irregularities that enhance the microbial adherence of certain species (eg, coagulase-negative staphylococci, *Acinetobacter calcoaceticus*, and *Pseudomonas aeruginosa*^{29–31}); catheters made of these materials are especially vulnerable to microbial colonization and subsequent infection. Additionally, certain catheter materials are more thrombogenic than others, a characteristic that also might predispose to catheter colonization and catheter-related infection.^{31,32} This association has led to emphasis on preventing catheter-related thrombus as an additional mechanism for reducing CRBSI.

The adherence properties of a given microorganism also are important in the pathogenesis of catheter-related infection. For example, *S aureus* can adhere to host proteins (eg, fibronectin) commonly present on catheters.^{33,34} Also, coagulase-negative staphylococci adhere to polymer surfaces more readily than do other pathogens (eg, *Escherichia coli* or *S aureus*). Additionally, certain strains of coagulase-negative staphylococci produce an extracellular polysaccharide often referred to as “slime.”^{35,36} In the presence of catheters, this slime potentiates the pathogenicity of coagulase-negative staphylococci by allowing them to withstand host defense mechanisms (eg, acting as a barrier to engulfment and killing by polymorphonuclear leukocytes) or by making them less susceptible to antimicrobial agents (eg, forming a matrix that binds antimicrobials before their contact with the organism cell wall).³⁷ Certain *Candida* spp, in the presence of glucose-containing fluids, might produce slime similar to that of their bacterial counterparts, potentially explaining

TABLE 3. Most Common Pathogens Isolated From Bloodstream Infections [^{12,15}]

Pathogen	1986–1989 (%)	1992–1999 (%)
Coagulase-negative staphylococci	27	37
<i>S aureus</i>	16	13
<i>Enterococcus</i>	8	13
Gram-negative rods	19	14
<i>E coli</i>	6	2
<i>Enterobacter</i>	5	5
<i>P aeruginosa</i>	4	4
<i>K pneumoniae</i>	4	3
<i>Candida</i> species	8	8

the increased proportion of BSIs caused by fungal pathogens among patients receiving parenteral nutrition fluids.³⁸

STRATEGIES FOR PREVENTION OF CATHETER-RELATED INFECTIONS IN ADULT AND PEDIATRIC PATIENTS

Quality Assurance and Continuing Education

Measures to minimize the risk for infection associated with intravascular therapy should strike a balance between patient safety and cost effectiveness. As knowledge, technology, and health-care settings change, infection control and prevention measures also should change. Well-organized programs that enable health-care providers to provide, monitor, and evaluate care and to become educated are critical to the success of this effort. Reports spanning the past two decades have consistently demonstrated that risk for infection declines following standardization of aseptic care,^{39–43} and that insertion and maintenance of intravascular catheters by inexperienced staff might increase the risk for catheter colonization and CRBSI.^{43,44} Specialized “IV teams” have shown unequivocal effectiveness in reducing the incidence of catheter-related infections and associated complications and costs.^{45–45} Additionally, infection risk increases with nursing staff reductions below a critical level.⁴⁸

Site of Catheter Insertion

The site at which a catheter is placed influences the subsequent risk for catheter-related infection and phlebitis. The influence of site on the risk for catheter infections is related in part to the risk for thrombophlebitis and density of local skin flora.

Phlebitis has long been recognized as a risk for infection. For adults, lower extremity insertion sites are associated with a higher risk for infection than are upper extremity sites.^{49–51} In addition, hand veins have a lower risk for phlebitis than do veins on the wrist or upper arm.⁵²

The density of skin flora at the catheter insertion site is a major risk factor for CRBSI. Authorities recommend that CVCs be placed in a subclavian site instead of a jugular or femoral site to reduce the risk for infection. No randomized trial satisfactorily has compared infection rates for catheters placed in jugular, subclavian, and femoral sites. Catheters inserted into an internal jugular vein have been associated with higher risk for infection than those inserted into a subclavian or femoral vein.^{22,53,54}

Femoral catheters have been demonstrated to have relatively high colonization rates when used in adults.⁵⁵ Femoral catheters should be avoided, when possible, because they are associated with a higher risk for deep venous thrombosis than are internal jugular or subclavian catheters.^{56–60} and because of a presumption that such catheters are more likely to become infected. However, studies in pediatric patients have demonstrated that femoral catheters have a low incidence of mechanical complications and might have an equivalent infection rate to that of nonfemoral catheters.^{61–63} Thus, in adult patients, a

subclavian site is preferred for infection control purposes, although other factors (eg, the potential for mechanical complications, risk for subclavian vein stenosis, and catheter-operator skill) should be considered when deciding where to place the catheter. In a meta-analysis of eight studies, the use of bedside ultrasound for the placement of CVCs substantially reduced mechanical complications compared with the standard landmark placement technique (RR = 0.22; 95% confidence interval [CI] = 0.10–0.45).⁶⁴ Consideration of comfort, security, and maintenance of asepsis as well as patient-specific factors (eg, pre-existing catheters, anatomic deformity, and bleeding diathesis), RR of mechanical complications (eg, bleeding and pneumothorax), the availability of bedside ultrasound, and the risk for infection should guide site selection.

Type of Catheter Material

Teflon or polyurethane catheters have been associated with fewer infectious complications than catheters made of polyvinyl chloride or polyethylene.^{27,65,66} Steel needles used as an alternative to catheters for peripheral venous access have the same rate of infectious complications as do Teflon catheters.^{67,68} However, the use of steel needles frequently is complicated by infiltration of intravenous (IV) fluids into the subcutaneous tissues, a potentially serious complication if the infused fluid is a vesicant.⁶⁸

Hand Hygiene and Aseptic Technique

For short peripheral catheters, good hand hygiene before catheter insertion or maintenance, combined with proper aseptic technique during catheter manipulation, provides protection against infection. Good hand hygiene can be achieved through the use of either a waterless, alcohol-based product⁶⁹ or an antibacterial soap and water with adequate rinsing.⁷⁰ Appropriate aseptic technique does not necessarily require sterile gloves; a new pair of disposable non-sterile gloves can be used in conjunction with a “no-touch” technique for the insertion of peripheral venous catheters. However, gloves are required by the Occupational Safety and Health Administration as standard precautions for the prevention of blood-borne pathogen exposure.

Compared with peripheral venous catheters, CVCs carry a substantially greater risk for infection; therefore, the level of barrier precautions needed to prevent infection during insertion of CVCs should be more stringent. Maximal sterile barrier precautions (eg, cap, mask, sterile gown, sterile gloves, and large sterile drape) during the insertion of CVCs substantially reduces the incidence of CRBSI compared with standard precautions (eg, sterile gloves and small drapes).^{22,71} Although the efficacy of such precautions for insertion of PICCs and midline catheters has not been studied, the use of maximal barrier precautions also is probably applicable to PICCs.

Skin Antisepsis

In the United States, povidone iodine has been the most widely used antiseptic for cleansing arterial catheter and CVC-insertion sites.⁷² However, in one

study, preparation of central venous and arterial sites with a 2% aqueous chlorhexidine gluconate lowered BSI rates compared with site preparation with 10% povidone-iodine or 70% alcohol.⁷³ Commercially available products containing chlorhexidine have not been available until recently; in July 2000, the US Food and Drug Administration (FDA) approved a 2% tincture of chlorhexidine preparation for skin antiseptics. Other preparations of chlorhexidine might not be as effective. Tincture of chlorhexidine gluconate 0.5% is no more effective in preventing CRBSI or CVC colonization than 10% povidone iodine, as demonstrated by a prospective, randomized study of adults.⁷⁴ However, in a study involving neonates, 0.5% chlorhexidine reduced peripheral IV colonization compared with povidone iodine (20/418 versus 38/408 catheters; $p = 0.01$).⁷⁵ This study, which did not include CVCs, had an insufficient number of participants to assess differences in BSI rates. A 1% tincture of chlorhexidine preparation is available in Canada and Australia, but not yet in the United States. No published trials have compared a 1% chlorhexidine preparation to povidone-iodine.

Catheter Site Dressing Regimens

Transparent, semipermeable polyurethane dressings have become a popular means of dressing catheter insertion sites. Transparent dressings reliably secure the device, permit continuous visual inspection of the catheter site, permit patients to bathe and shower without saturating the dressing, and require less frequent changes than do standard gauze and tape dressings; the use of these dressings saves personnel time.

In the largest controlled trial of dressing regimens on peripheral catheters, the infectious morbidity associated with the use of transparent dressings on approximately 2,000 peripheral catheters was examined.⁶⁵ Data from this study suggest that the rate of colonization among catheters dressed with transparent dressings (5.7%) is comparable to that of those dressed with gauze (4.6%) and that no clinically substantial differences exist in either the incidences of catheter-site colonization or phlebitis. Furthermore, these data suggest that transparent dressings can be safely left on peripheral venous catheters for the duration of catheter insertion without increasing the risk for thrombophlebitis.⁶⁵

A meta-analysis has assessed studies that compared the risk for catheter-related BSIs for groups using transparent dressings versus groups using gauze dressing.⁷⁶ The risk for CRBSIs did not differ between the groups. The choice of dressing can be a matter of preference. If blood is oozing from the catheter insertion site, gauze dressing might be preferred.

In a multi-center study, a chlorhexidine-impregnated sponge (Biopatch) placed over the site of short-term arterial and CVCs reduced the risk for catheter colonization and CRBSI.⁷⁷ No adverse systemic effects resulted from use of this device.

Catheter Securement Devices

Sutureless securement devices can be advantageous over suture in preventing catheter-related BSIs. One study, which involved only a limited number of patients and was underpowered, compared a sutureless device with suture for the securement of PICCS; in this study, CRBSI was reduced in the group of patients that received the sutureless device.⁷⁸

In-Line Filters

In-line filters reduce the incidence of infusion-related phlebitis.^{79,80} No data support their efficacy in preventing infections associated with intravascular catheters and infusion systems. Proponents of filters cite several potential benefits to using these filters, including 1) reducing the risk for infection from contaminated infusate or proximal contamination (ie, introduced proximal to the filter); 2) reducing the risk for phlebitis in patients who require high doses of medication or in those in whom infusion-related phlebitis already has occurred; 3) removing particulate matter that might contaminate IV fluids⁸¹; and 4) filtering endotoxin produced by gram-negative organisms in contaminated infusate.⁸² These theoretical advantages should be tempered by the knowledge that infusate-related BSI is rare and that filtration of medications or infusates in the pharmacy is a more practical and less costly way to remove the majority of particulates. Furthermore, in-line filters might become blocked, especially with certain solutions (eg, dextran, lipids, and mannitol), thereby increasing the number of line manipulations and decreasing the availability of administered drugs.⁸³ Thus, for reducing the risk for CRBSI, no strong recommendation can be made in favor of using in-line filters.

Antimicrobial/Antiseptic Impregnated Catheters and Cuffs

Certain catheters and cuffs that are coated or impregnated with antimicrobial or antiseptic agents can decrease the risk for CRBSI and potentially decrease hospital costs associated with treating CRBSIs, despite the additional acquisition cost of an antimicrobial/antiseptic impregnated catheter.⁸⁴ All of the studies involving antimicrobial/antiseptic impregnated catheters have been conducted using triple-lumen, noncuffed catheters in adult patients whose catheters remained in place <30 days. Although all of the studies have been conducted in adults, these catheters have been approved by FDA for use in patients weighing >3 kg. No antiseptic or antimicrobial impregnated catheters currently are available for use in weighing <3 kg.

Chlorhexidine/Silver Sulfadiazine

Catheters coated with chlorhexidine/silver sulfadiazine only on the external luminal surface have been studied as a means to reduce CRBSI. Two meta-analyses^{2,85} demonstrated that such catheters reduced the risk for CRBSI compared with standard noncoated catheters. The mean duration of catheter placement in one meta-analysis ranged from 5.1 to

11.2 days.⁸⁶ The half-life of antimicrobial activity against *S epidermidis* is 3 days in vitro for catheters coated with chlorhexidine/silver sulfadiazine; this antimicrobial activity decreases over time.⁸⁷ The benefit for the patients who receive these catheters will be realized within the first 14 days.⁸⁶ A second-generation catheter is now available with chlorhexidine coating both the internal and external luminal surfaces. The external surface has three times the amount of chlorhexidine and extended release of the surface bound antiseptics than that in the first generation catheters. The external surface coating of chlorhexidine is combined with silver-sulfadiazine, and the internal surface is coated with chlorhexidine alone. Preliminary studies indicate that prolonged anti-infective activity provides improved efficacy in preventing infections.⁸⁸ Although rare, anaphylaxis has been reported with the use of these chlorhexidine/silver sulfadiazine catheters in Japan.⁸⁹ Whether patients will become colonized or infected with organisms resistant to chlorhexidine/silver sulfadiazine has not been determined.⁸⁶

Chlorhexidine/silver sulfadiazine catheters are more expensive than standard catheters. However, one analysis has suggested that the use of chlorhexidine/silver sulfadiazine catheters should lead to a cost savings of \$68 to \$391 per catheter⁹⁰ in settings in which the risk for CRBSI is high despite adherence to other preventive strategies (eg, maximal barrier precautions and aseptic techniques). Use of these catheters might be cost effective in ICU patients, burn patients, neutropenic patients, and other patient populations in which the rate of infection exceeds 3.3 per 1,000 catheter days.⁸⁶

Minocycline/Rifampin

In a multicenter randomized trial, CVCs impregnated on both the external and internal surfaces with minocycline/rifampin were associated with lower rates of CRBSI when compared with the first-generation chlorhexidine-silver sulfadiazine impregnated catheters.⁹¹ The beneficial effect began after day 6 of catheterization. None of the catheters were evaluated beyond 30 days. No minocycline/rifampin-resistant organisms were reported. However, in vitro data indicate that these impregnated catheters could increase the incidence of minocycline and rifampin resistance among pathogens, especially staphylococci. The half-life of antimicrobial activity against *S epidermidis* is 25 days with catheters coated with minocycline/rifampin, compared with 3 days for the first-generation catheters coated with chlorhexidine/silver sulfadiazine in vitro.⁸⁷ In vivo, the duration of antimicrobial activity of the minocycline/rifampin catheter is longer than that of the first-generation chlorhexidine/silver sulfadiazine catheter.⁹¹ No comparative studies have been published using the second-generation chlorhexidine/silver sulfadiazine catheter. Studies are needed to evaluate whether the improved performance of the minocycline/rifampin catheters results from the antimicrobial agents used or from the coating of both the internal and external surfaces. As with chlorhexidine/silver sulfadiazine catheters, some clinicians have recom-

mended that the minocycline/rifampin catheters be considered in patient populations when the rate of CRBSI exceeds 3.3 per 1,000 catheter days.⁸⁶ Others suggest that reducing all rates of CRBSI should be the goal.⁹² The decision to use chlorhexidine/silver sulfadiazine or minocycline/rifampin impregnated catheters should be based on the need to enhance prevention of CRBSI after standard procedures have been implemented (eg, educating personnel, using maximal sterile barrier precautions, and using 2% chlorhexidine skin antiseptics) and then balanced against the concern for emergence of resistant pathogens and the cost of implementing this strategy.

Platinum/Silver

Ionic metals have broad antimicrobial activity and are being used in catheters and cuffs to prevent CRBSI. A combination platinum/silver impregnated catheter is available in Europe and has recently been approved by FDA for use in the United States. Although these catheters are being marketed for their antimicrobial properties, no published studies have been presented to support an antimicrobial effect.

Silver Cuffs

Ionic silver has been used in subcutaneous collagen cuffs attached to CVCs.⁹³ The ionic silver provides antimicrobial activity and the cuff provides a mechanical barrier to the migration of microorganisms along the external surface of the catheter. In studies of catheters left in place ≥ 20 days, the cuff failed to reduce the incidence of CRBSI.^{94,95} Two other studies of short-term catheters could not demonstrate efficacy because of the minimal number of CRBSIs observed.^{93,96}

Systemic Antibiotic Prophylaxis

No studies have demonstrated that oral or parenteral antibacterial or antifungal drugs might reduce the incidence of CRBSI among adults.⁹⁷⁻⁹⁹ However, among low birth weight infants, two studies have assessed vancomycin prophylaxis; both demonstrated a reduction in CRBSI but no reduction in mortality.^{100,101} Because the prophylactic use of vancomycin is an independent risk factor for the acquisition of vancomycin-resistant enterococcus (VRE),¹⁰² the risk for acquiring VRE likely outweighs the benefit of using prophylactic vancomycin.

Antibiotic/Antiseptic Ointments

Povidone-iodine ointment applied at the insertion site of hemodialysis catheters has been studied as a prophylactic intervention to reduce the incidence of catheter-related infections. One randomized study of 129 hemodialysis catheters demonstrated a reduction in the incidence of exit-site infections, catheter-tip colonization, and BSIs with the routine use of povidone-iodine ointment at the catheter insertion site compared with no ointment at the insertion site.¹⁰³

Several studies have evaluated the effectiveness of mupirocin ointment applied at the insertion sites of CVCs as a means to prevent CRBSI.¹⁰⁴⁻¹⁰⁶ Although mupirocin reduced the risk for CRBSI,¹⁰⁶ mupirocin ointment also has been associated with mupirocin

resistance,^{107,108} and might adversely affect the integrity of polyurethane catheters.^{109,110}

Nasal carriers of *S aureus* have a higher risk for acquiring CRBSI than do noncarriers.^{103,111} Mupirocin ointment has been used intranasally to decrease nasal carriage of *S aureus* and lessen the risk for CRBSI. However, resistance to mupirocin develops in both *S aureus* and coagulase-negative staphylococci soon after routine use of mupirocin is instituted.^{107,108}

Other antibiotic ointments applied to the catheter insertion site also have been studied and have yielded conflicting results.^{112–114} In addition, rates of catheter colonization with *Candida* spp might be increased with the use of antibiotic ointments that have no fungicidal activity.^{112,114} To avoid compromising the integrity of the catheter, any ointment that is applied to the catheter insertion site should be checked against the catheter and ointment manufacturers' recommendations regarding compatibility.

Antibiotic Lock Prophylaxis

To prevent CRBSI, antibiotic lock prophylaxis has been attempted by flushing and filling the lumen of the catheter with an antibiotic solution and leaving the solution to dwell in the lumen of the catheter. Three studies have demonstrated the usefulness of such prophylaxis in neutropenic patients with long-term catheters.^{115–117} In two of the studies, patients received either heparin alone (10 U/ml) or heparin plus 25 micrograms/ml of vancomycin. The third study compared vancomycin/ciprofloxacin/heparin (VCH) to vancomycin/heparin (VH) and then to heparin alone. The rate of CRBSI with vancomycin-susceptible organisms was significantly lower (VCH, $p = 0.022$; VH, $p = 0.028$) and the time to the first episode of bacteremia with vancomycin-susceptible organisms was substantially longer (VCH, $p = 0.036$; VH, $p = 0.011$) in patients receiving either vancomycin/ciprofloxacin/heparin or vancomycin/heparin compared with heparin alone.^{115–117} One study involving a limited number of children revealed no difference in rates of CRBSI between children receiving a heparin flush compared with those receiving heparin and vancomycin.¹¹⁸ However, because the use of vancomycin is an independent risk factor for the acquisition of VRE,¹⁰² this practice is not recommended routinely.

An anticoagulant/antimicrobial combination comprising minocycline and ethylenediaminetetraacetic acid (EDTA) has been proposed as a lock solution because it has antibiofilm and antimicrobial activity against gram-positive, gram-negative, and *Candida* organisms,¹¹⁹ as well as anticoagulant properties. However, no controlled or randomized trials have demonstrated its efficacy.

Anticoagulants

Anticoagulant flush solutions are used widely to prevent catheter thrombosis. Because thrombi and fibrin deposits on catheters might serve as a nidus for microbial colonization of intravascular catheters,^{120,121} the use of anticoagulants might have a role in the prevention of CRBSI.

In a meta-analysis evaluating the benefit of heparin prophylaxis (3 U/ml in TPN, 5,000 U every 6 or 12 hours flush, or 2,500 U low molecular weight heparin subcutaneously) in patients with short-term CVCs, the risk for catheter-related central venous thrombosis was reduced with the use of prophylactic heparin.¹²² However, no substantial difference in the rate for CRBSI was observed. Because the majority of heparin solutions contain preservatives with antimicrobial activity, whether any decrease in the rate of CRBSI is a result of the reduced thrombus formation, the preservative, or both is unclear.

The majority of pulmonary artery, umbilical, and central venous catheters are available with a heparin-bonded coating. The majority are heparin-bonded with benzalkonium chloride, which provides the catheters with antimicrobial activity¹²³ and provides an anti-thrombotic effect.¹²⁴

Warfarin also has been evaluated as a means for reducing CRBSI by reducing thrombus formation on catheters.^{125,126} In patients with long-term CVCs, low-dose warfarin (ie, 1 mg/day) reduced the incidence of catheter thrombus. No data demonstrate that warfarin reduces the incidence of CRBSI.

Replacement of Catheters

Peripheral Venous Catheters

Scheduled replacement of intravascular catheters has been proposed as a method to prevent phlebitis and catheter-related infections. Studies of short peripheral venous catheters indicate that the incidence of thrombophlebitis and bacterial colonization of catheters increases when catheters are left in place >72 hours.^{66,67,127} However, rates of phlebitis are not substantially different in peripheral catheters left in place 72 hours compared with 96 hours.¹²⁸ Because phlebitis and catheter colonization have been associated with an increased risk for catheter-related infection, short peripheral catheter sites commonly are rotated at 72–96-hour intervals to reduce both the risk for infection and patient discomfort associated with phlebitis.

Midline Catheters

Midline catheters have been associated with lower rates of phlebitis than short peripheral catheters and with lower rates of infection than CVCs.^{129–131} In one prospective study of 140 midline catheters, their use was associated with a BSI rate of 0.8 per 1,000 catheter-days.¹³¹ No specific risk factors, including duration of catheterization, were associated with infection. Midline catheters were in place a median of 7 days, but for as long as 49 days. Although the findings of this study suggested that midline catheters can be changed only when there is a specific indication, no prospective, randomized studies have assessed the benefit of routine replacement as a strategy to prevent CRBSI associated with midline catheters.

CVCs, Including PICCs and Hemodialysis Catheters

Catheter replacement at scheduled time intervals as a method to reduce CRBSI has not lowered rates.

Two trials have assessed a strategy of changing the catheter every 7 days compared with a strategy of changing catheters as needed.^{132,133} One of these studies involved 112 surgical ICU patients needing CVCs, pulmonary artery catheters, or peripheral arterial catheters,¹³² whereas the other study involved only subclavian hemodialysis catheters.¹³³ In both studies, no difference in CRBSI was observed in patients undergoing scheduled catheter replacement every 7 days compared with patients whose catheters were replaced as needed.

Scheduled guidewire exchanges of CVCs is another proposed strategy for preventing CRBSI. The results of a meta-analysis of 12 randomized controlled trials assessing CVC management failed to prove any reduction of CRBSI rates through routine replacement of CVCs by guidewire exchange compared with catheter replacement on an as-needed basis.¹³⁴ Thus, routine replacement of CVCs is not necessary for catheters that are functioning and have no evidence of causing local or systemic complications.

Catheter replacement over a guidewire has become an accepted technique for replacing a malfunctioning catheter or exchanging a pulmonary artery catheter for a CVC when invasive monitoring no longer is needed. Catheter insertion over a guidewire is associated with less discomfort and a significantly lower rate of mechanical complications than are those percutaneously inserted at a new site¹³⁵; in addition, this technique provides a means of preserving limited venous access in some patients. Replacement of temporary catheters over a guidewire in the presence of bacteremia is not an acceptable replacement strategy, because the source of infection is usually colonization of the skin tract from the insertion site to the vein.^{22,135} However, in selected patients with tunneled hemodialysis catheters and bacteremia, catheter exchange over a guidewire, in combination with antibiotic therapy, might be an alternative as a salvage strategy in patients with limited venous access.^{136–139}

Hemodialysis Catheters

The use of catheters for hemodialysis is the most common factor contributing to bacteremia in dialysis patients.^{140,141} The RR for bacteremia in patients with dialysis catheters is sevenfold the risk for patients with primary arteriovenous fistulas.¹⁴² Despite the National Kidney Foundation's effort to reduce the number of hemodialysis patients maintained with catheter access, catheter use increased from 12.7% in 1995 to 22.2% in 1999.¹⁴³ Rates for bacteremia per 100 patient months were 0.2 for arteriovenous fistulas, 0.5 for grafts, 5.0 for cuffed catheters, and 8.5 for noncuffed catheters (CDC, unpublished data, 1999).

To reduce the rate of infection, hemodialysis catheters should be avoided in favor of arteriovenous fistulas and grafts. If temporary access is needed for dialysis, a cuffed catheter is preferable to a noncuffed catheter, even in the ICU setting, if the catheter is expected to stay in place for >3 weeks.^{11,144}

Pulmonary Artery Catheters

Pulmonary artery catheters are inserted through a Teflon introducer and typically remain in place an average of 3 days. The majority of pulmonary artery catheters are heparin bonded, which reduces not only catheter thrombosis but also microbial adherence to the catheter.¹⁴⁵ Meta-analysis indicates that standard nonheparin-bonded pulmonary artery catheter rates of CRBSI are 5.5 per 1,000 catheter days; for heparin-bonded pulmonary artery catheters, this rate is 2.6 per 1,000 catheter days.¹¹ Because the majority of pulmonary artery catheters are heparin-bonded, the RR of infection with these catheters is similar to that of CVC (2.6 versus 2.3 per 1,000 catheter days).¹¹

A prospective study of 442 pulmonary artery catheters demonstrated an increased risk for CRBSI after 5 days (0/442 CRBSI before 5 days versus 5/442 CRBSI after 5 days; $P < 0.001$).¹⁴⁶ A prospective observational study of 71 pulmonary artery catheters demonstrated higher infection rates in catheters left in place longer than 7 days (2% before 7 days versus 16% after 7 days; $P = 0.056$).¹⁴⁷ However, no studies indicate that catheter replacement at scheduled time intervals is an effective method to reduce CRBSI.^{132,135} In patients who continue to require hemodynamic monitoring, pulmonary artery catheters do not need to be changed more frequently than every 7 days. No specific recommendation can be made regarding routine replacement of catheters that need to be in place for >7 days.

Pulmonary artery catheters are usually packaged with a thin plastic sleeve that prevents touch contamination when placed over the catheter. In a study of 166 catheters, patients who were randomly assigned to have their catheters self-contained within this sleeve had a reduced risk for CRBSI compared with those who had a pulmonary artery catheter placed without the sleeve ($P = 0.002$).¹⁴⁸

Peripheral Arterial Catheters

Peripheral arterial catheters are usually inserted into the radial or femoral artery and permit continuous blood pressure monitoring and blood gas measurements. The rate of CRBSI is comparable to that of temporary CVCs (2.9 versus 2.3 per 1,000 catheter days).¹¹ One study of peripheral arterial catheters demonstrated no difference in infection rates between changing catheters at scheduled times and changing arterial catheters on an as-needed basis.¹³² One observational study of 71 arterial catheters revealed that 10 local infections and four CRBSIs occurred in patients who had peripheral arterial catheters in place for >4 days compared with one local infection and no CRBSIs in patients whose catheters were in place <4 days ($P < 0.05$).¹⁴⁷ Because the risk for CRBSI is likely similar to that of short-term CVCs, arterial catheters can be approached in a similar way. No specific recommendation can be made regarding replacement of catheters that need to be in place for >5 days.

APPENDIX B. Summary of Recommended Frequency of Replacements for Catheters, Dressings, Administration Sets, and Fluids

Catheter	Relocation and Replacement of Device	Replacement of Catheter Site Dressing	Replacement of Administration Sets	Hang Time for Parenteral Fluids
Peripheral venous catheters	In adults, replace catheter and rotate site no more frequently than every 72–96 h. Replace catheters inserted under emergency basis and insert a new catheter at a different site within 48 h. In pediatric patients, do not replace peripheral catheters unless clinically indicated.	Replace dressing when the catheter is removed or replaced or when the dressing becomes damp, loosened, or soiled. Replace dressings more frequently in diaphoretic patients. In patients who have large bulky dressings that prevent palpation or direct visualization of the catheter insertion site, remove the dressing and visually inspect the catheter at least daily and apply a new dressing.	Replace IV tubing, including add-on devices, no more frequently than at 72-h intervals unless clinically indicated. Replace tubing used to administer blood, blood products, or lipid emulsions within 24 h of initiating the infusion. No recommendation for replacement of tubing used for intermittent infusions. Consider short extension tubing connected to the catheter to be a portion of the device. Replace such extension tubing when the catheter is changed.	No recommendation for the hang time of IV fluids, including non-lipid-containing parenteral nutrition fluids. Complete infusion of lipid-containing parenteral nutrition fluids (eg, 3-in-1 solutions) within 24 h of hanging the fluid. Complete infusion of lipid emulsions alone within 12 h of hanging the fluid. Complete infusions of blood products within 4 h of hanging the product.
Midline catheters	No recommendation for the frequency of the catheter replacement	As above.	As above.	As above.
Peripheral arterial catheters	In adults, do not replace catheters routinely to prevent catheter-related infection. In pediatric patients, no recommendation for the frequency of catheter replacement. Replace disposable or reusable transducers at 96-hour intervals. Replace continuous flush device at the time the transducer is replaced.	Replace dressing when the catheter is replaced; when the dressing becomes damp, loosened, or soiled; or when inspection of the site is necessary.	Replace the IV tubing at the time the transducer is replaced (ie, 96-h intervals).	Replace the flush solution at the time the transducer is replaced (ie, 96-h intervals).
CVCs including peripherally inserted central catheters and hemodialysis catheters*	Do not routinely replace catheters.	Replace gauze dressings every 2 d and transparent dressings every 7 d on short-term catheters. Replace the dressing when the catheter is replaced; when the dressing becomes damp, loosened, or soiled; or when inspection of the site is necessary.	Replace IV tubing and add-on devices no more frequently than at 72-h intervals. Replace tubing used to administer blood products or lipid emulsions within 24 h of initiating the infusion.	No recommendation for the hang time of IV fluids, including non-lipid-containing parenteral nutrition fluids. Complete infusions of lipid-containing fluids within 24 h of hanging the fluid.
Pulmonary artery catheters	Do not replace catheter to prevent catheter-related infection.	As above.	As above.	As above.
Umbilical catheters	Do not routinely replace catheters.	Not applicable.	Replace IV tubing and add-on devices no more frequently than at 72-h intervals. Replace tubing used to administer blood products or lipid emulsions within 24 h of initiating the infusion.	No recommendations for the hang time of IV fluids, including non-lipid-containing parenteral nutrition fluids. Complete infusion of lipid-containing fluids within 24 h of hanging the fluid.

* Includes nontunneled catheters, tunneled catheters, and totally implanted devices.

The optimal interval for routine replacement of IV administration sets has been examined in three well-controlled studies. Data from each of these studies reveal that replacing administration sets no more frequently than 72 hours after initiation of use is safe and cost-effective.^{149–151} Data from a more recent study demonstrated that rates of phlebitis were not substantially different if administration sets were left in place 96 hours compared with 72 hours.¹²⁸ When a fluid that enhances microbial growth is infused (eg, lipid emulsions and blood products), more frequent changes of administration sets are indicated, because these products have been identified as independent risk factors for CRBSI.^{152–158}

Stopcocks (used for injection of medications, administration of IV infusions, and collection of blood samples) represent a potential portal of entry for microorganisms into vascular access catheters and IV fluids. Stopcock contamination is common, occurring in 45% and 50% in the majority of series. Whether such contamination is a substantial entry point of CRBSI has been difficult to prove.

“Piggyback” systems are used as an alternative to stopcocks. However, they also pose a risk for contamination of the intravascular fluid if the device entering the rubber membrane of an injection port is exposed to air or comes into direct contact with nonsterile tape used to fix the needle to the port. Modified piggyback systems have the potential to prevent contamination at these sites.¹⁵⁹

Needleless Intravascular Catheter Systems

Attempts to reduce the incidence of sharp injuries and the resultant risk for transmission of bloodborne infections to health-care workers have led to the design and introduction of needleless infusion systems. When the devices are used according to manufacturers’ recommendations, they do not substantially affect the incidence of CRBSI.^{160–167}

Multidose Parenteral Medication Vials

Parenteral medications commonly are dispensed in multidose, parenteral medication vials that might be used for prolonged periods for one or more patients. Although the overall risk for extrinsic contamination of multidose vials is likely minimal,¹⁶⁸ the consequences of contamination might result in life-threatening infection.^{169,170} Single-use vials are frequently preservative-free and might pose a risk for contamination if they are punctured several times.

SPECIAL CONSIDERATIONS FOR INTRAVASCULAR CATHETER-RELATED INFECTIONS IN PEDIATRIC PATIENTS

Prevention of CRBSI in children requires additional considerations, although only certain studies have been performed specifically in children. Pediatric data have been derived largely from studies in neonatal or pediatric ICUs and pediatric oncology patients.

Epidemiology

As in adults, the majority of BSIs in children are associated with the use of an intravascular catheter. From 1995 through 2000, the pooled mean catheter-associated BSI rate for all pediatric ICUs reporting data to NNIS was 7.7 per 1,000 catheter days.^{171,172} Umbilical catheter and CVC-associated BSI rates for neonatal ICUs ranged from 11.3 per 1,000 catheter days in children with birth weight <1,000 g to 4.0 per 1,000 catheter days in children whose birth weight was >2,500 g.¹⁷¹ Catheter utilization rates were comparable in adult and pediatric ICUs.^{172,173}

Microbiology

As in adults, the majority of CRBSIs in children are caused by coagulase-negative staphylococci. During 1992–1999, these bacteria accounted for 37.7% of BSIs in pediatric ICUs reporting to NNIS.¹² Exposure to lipids has been identified as an independent risk factor for development of coagulase-negative staphylococcal bacteremia in very low birth weight infants (ie, those weighing <1,000 g) (odds ratio [OR] = 9.4; 95% CI = 1.2–74.2),¹⁵⁵ as well as candidemia in the neonatal ICU (OR = 5.33; 95% CI = 1.23–48.4).¹⁵⁴ Gram-negative bacteria accounted for 25% of BSIs reported in pediatric ICUs,¹⁷² whereas enterococci and *Candida* spp accounted for 10% and 9%, respectively.¹⁷²

Peripheral Venous Catheters

As in adults, the use of peripheral venous catheters in pediatric patients might be complicated by phlebitis, infusion extravasation, and catheter infection.¹⁷⁴ Catheter location, infusion of parenteral nutritional fluids with continuous IV lipid emulsions, and length of ICU stay before catheter insertion have all increased pediatric patients’ risk for phlebitis. However, contrary to the risk in adults, the risk for phlebitis in children has not increased with the duration of catheterization.^{174,175}

Peripheral Arterial Catheters

In a prospective study of 340 peripheral arterial catheters in children, the following two risk factors for catheter-related infection were identified: 1) use of an arterial system that permitted backflow of blood into the pressure tubing and 2) duration of catheterization.¹⁷⁶ Although a correlation was found between duration of arterial catheterization and risk for catheter colonization, the risk remained constant for 2–20 days at 6.2%.¹⁷⁶

Umbilical Catheters

Although the umbilical stump becomes heavily colonized soon after birth, umbilical-vessel catheterization often is used for vascular access in newborn infants. Umbilical vessels can be cannulated easily and permit both collection of blood samples and measurement of hemodynamic status. The incidences of catheter colonization and BSI are similar for umbilical vein catheters and umbilical artery catheters. In several studies, an estimated 40%–55% of umbilical artery catheters were colonized and 5%

resulted in CRBSI; umbilical vein catheters were associated with colonization in 22%–59% of cases^{177–179} and with CRBSI in 3%–8% of cases.¹⁷⁸ Although CRBSI rates are similar for umbilical catheters in the high position (ie, above the diaphragm) compared with the low position (ie, below the diaphragm and above the aortic bifurcation), catheters placed in the high position result in a lower incidence of vascular complications without an increase in adverse sequelae.¹⁷⁸

Risk factors for infection differ for umbilical artery and umbilical vein catheters. In one study, neonates with very low birth weight who also received antibiotics for >10 days were at increased risk for umbilical artery CRBSIs.¹⁷⁸ In comparison, those with higher birth weight and receipt of parenteral nutrition fluids were at increased risk for umbilical vein CRBSI. Duration of catheterization was not an independent risk factor for infection of either type of umbilical catheter.

CVCs

Because of the limited vascular sites in children, attention should be given to the frequency with which catheters are replaced in these patients. In a study in which survival analysis techniques were used to examine the relation between the duration of central venous catheterization and complications in pediatric ICU patients, all of the patients studied ($n = 397$) remained uninfected for a median of 23.7 days.¹⁸⁰ In addition, no relation was found between duration of catheterization and the daily probability of infection ($r = 0.21$; $P > 0.1$), suggesting that routine replacement of CVCs likely does not reduce the incidence of catheter-related infection.¹⁸⁰

Catheter Site Care

Although data regarding the use of the chlorhexidine-impregnated sponge (Biopatch in children are limited, one randomized, controlled study involving 705 neonates reported a substantial decrease in colonized catheter tips in infants in the Biopatch group compared with the group that had standard dressings (15% versus 24%; RR = 0.6; 95% CI = 0.5–0.9), but no difference in the rates of CRBSI or BSI without a source. Biopatch was associated with localized contact dermatitis in infants of very low birth weight. Of 98 neonates with very low birth weight, 15 (15%) developed localized contact dermatitis; four (1.5%) of 237 neonates weighing >1,000 g developed this reaction ($P < 0.0001$). Infants with gestational age <26 weeks who had CVCs placed at age <8 days were at increased risk for having localized contact dermatitis, whereas no infants in the control group developed this local reaction.¹⁸¹

Performance Indicators

Performance indicators for reducing CRBSI are 1) implementation of educational programs that include didactic and interactive components for those who insert and maintain catheters; 2) use of maximal sterile barrier precautions during catheter placement; 3) use of chlorhexidine for skin antisepsis; and 4) rates of catheter discontinuation when the catheter is

no longer essential for medical management. The impact these recommendations will have on individual institutions should be evaluated using specific performance indicators.

RECOMMENDATIONS FOR PLACEMENT OF INTRAVASCULAR CATHETERS IN ADULTS AND CHILDREN

These recommendations are designed to reduce the infectious complications associated with intravascular catheter use. Recommendations should be considered in the context of the institution's experience with catheter-related infections, experience with other adverse catheter-related complications (eg, thrombosis, hemorrhage, and pneumothorax), and availability of personnel skilled in the placement of intravascular devices. Recommendations are provided for 1) intravascular-catheter use in general; 2) specific devices; and 3) special circumstances (ie, intravascular-device use in pediatric patients and CVC use for parenteral nutrition and hemodialysis access). Recommendations regarding the frequency of replacing catheters, dressings, administration sets, and fluids also are provided (Appendix B).

As in previous guidelines issued by CDC and HICPAC, each recommendation is categorized on the basis of existing scientific data, theoretical rationale, applicability, and economic impact. The CDC/HICPAC system for categorizing recommendations is as follows:

Category IA. Strongly recommended for implementation and strongly supported by well-designed experimental, clinical, or epidemiologic studies.

Category IB. Strongly recommended for implementation and supported by some experimental, clinical, or epidemiologic studies, and a strong theoretical rationale.

Category IC. Required by state or federal regulations, rules, or standards.

Category II. Suggested for implementation and supported by suggestive clinical or epidemiologic studies or a theoretical rationale.

Unresolved issue. Represents an unresolved issue for which evidence is insufficient or no consensus regarding efficacy exists.

- I. Health-care worker education and training
 - A. Educate health-care workers regarding the indications for intravascular catheter use, proper procedures for the insertion and maintenance of intravascular catheters, and appropriate infection-control measures to prevent intravascular catheter-related infections.^{39,43,45–47,182–187} **Category IA**
 - B. Assess knowledge of and adherence to guidelines periodically for all persons who insert and manage intravascular catheters.^{39,43,46,182,188} **Category IA**
 - C. Ensure appropriate nursing staff levels in ICUs to minimize the incidence of CRBSIs.^{48,189,190} **Category IB**
- II. Surveillance
 - A. Monitor the catheter sites visually or by palpation through the intact dressing on a reg-

- ular basis, depending on the clinical situation of individual patients. If patients have tenderness at the insertion site, fever without obvious source, or other manifestations suggesting local or BSI, the dressing should be removed to allow thorough examination of the site.^{1,191–193} **Category IB**
- B. Encourage patients to report to their health-care provider any changes in their catheter site or any new discomfort. **Category II**
 - C. Record the operator, date, and time of catheter insertion and removal, and dressing changes on a standardized form. **Category II**
 - D. Do not routinely culture catheter tips.^{8,194,195} **Category IA**
- III. Hand hygiene
- A. Observe proper hand-hygiene procedures either by washing hands with conventional antiseptic-containing soap and water or with waterless alcohol-based gels or foams. Observe hand hygiene before and after palpating catheter insertion sites, as well as before and after inserting, replacing, accessing, repairing, or dressing an intravascular catheter. Palpation of the insertion site should not be performed after the application of antiseptic, unless aseptic technique is maintained.^{43,70,196–200} **Category IA**
 - B. Use of gloves does not obviate the need for hand hygiene.^{43,198,199} **Category IA**
- IV. Aseptic technique during catheter insertion and care
- A. Maintain aseptic technique for the insertion and care of intravascular catheters.^{22,71,201,202} **Category IA**
 - B. Wear clean or sterile gloves when inserting an intravascular catheter as required by the Occupational Safety and Health Administration Bloodborne Pathogens Standard. **Category IC.** Wearing clean gloves rather than sterile gloves is acceptable for the insertion of peripheral intravascular catheters if the access site is not touched after the application of skin antiseptics. Sterile gloves should be worn for the insertion of arterial and central catheters.^{201,203} **Category IA**
 - C. Wear clean or sterile gloves when changing the dressing on intravascular catheters. **Category IC**
- V. Catheter insertion
- Do not routinely use arterial or venous cut-down procedures as a method to insert catheters.^{204–206} **Category IA**
- VI. Catheter site care
- A. Cutaneous antiseptics
 1. Disinfect clean skin with an appropriate antiseptic before catheter insertion and during dressing changes. Although a 2% chlorhexidine-based preparation is preferred, tincture of iodine, an iodophor, or 70% alcohol can be used.^{73,75,207,208} **Category IA**
 2. No recommendation can be made for the use of chlorhexidine in infants aged <2 months. **Unresolved issue**
 3. Allow the antiseptic to remain on the insertion site and to air dry before catheter insertion. Allow povidone iodine to remain on the skin for at least 2 minutes, or longer if it is not yet dry before insertion.^{73,75,207,208} **Category IB**
 4. Do not apply organic solvents (eg, acetone and ether) to the skin before insertion of catheters or during dressing changes.²⁰⁹ **Category IA**
- VII. Catheter-site dressing regimens
- A. Use either sterile gauze or sterile, transparent, semipermeable dressing to cover the catheter site.^{146,210–212} **Category IA**
 - B. Tunneled CVC sites that are well healed might not require dressings. **Category II**
 - C. If the patient is diaphoretic, or if the site is bleeding or oozing, a gauze dressing is preferable to a transparent, semi-permeable dressing.^{146,210–212} **Category II**
 - D. Replace catheter-site dressing if the dressing becomes damp, loosened, or visibly soiled.^{146,210} **Category IB**
 - E. Change dressings at least weekly for adult and adolescent patients depending on the circumstances of the individual patient.²¹¹ **Category II**
 - F. Do not use topical antibiotic ointment or creams on insertion sites (except when using dialysis catheters) because of their potential to promote fungal infections and antimicrobial resistance.^{107,213} **Category IA** (See Central Venous Catheters, Including PICCs, Hemodialysis, and Pulmonary Artery Catheters, in Adult and Pediatric Patients, Section III.I.)
 - G. Do not submerge the catheter under water. Showering should be permitted if precautions can be taken to reduce the likelihood of introducing organisms into the catheter (eg, if the catheter and connecting device are protected with an impermeable cover during the shower).^{214,215} **Category II**
- VIII. Selection and replacement of intravascular catheters
- A. Select the catheter, insertion technique, and insertion site with the lowest risk for complications (infectious and noninfectious) for the anticipated type and duration of IV therapy.^{22,55,59,216–218} **Category IA**
 - B. Promptly remove any intravascular catheter that is no longer essential.^{219,220} **Category IA**
 - C. Do not routinely replace central venous or arterial catheters solely for the purposes of reducing the incidence of infection.^{134,135,221} **Category IB**
 - D. Replace peripheral venous catheters at least every 72–96 hours in adults to prevent phlebitis.¹²⁸ Leave peripheral venous catheters in place in children until IV therapy is com-

pleted, unless complications (eg, phlebitis and infiltration) occur.^{174,175,222,223} **Category IB**

- E. When adherence to aseptic technique cannot be ensured (ie, when catheters are inserted during a medical emergency), replace all catheters as soon as possible and after no longer than 48 hours.^{22,71,201,202} **Category II**
 - F. Use clinical judgment to determine when to replace a catheter that could be a source of infection (eg, do not routinely replace catheters in patients whose only indication of infection is fever). Do not routinely replace venous catheters in patients who are bacteremic or fungemic if the source of infection is unlikely to be the catheter.²²⁴ **Category II**
 - G. Replace any short-term CVC if purulence is observed at the insertion site, which indicates infection.^{224,225} **Category IB**
 - H. Replace all CVCs if the patient is hemodynamically unstable and CRBSI is suspected.^{224,225} **Category II**
 - I. Do not use guidewire techniques to replace catheters in patients suspected of having catheter-related infection.^{134,135} **Category IB**
- IX. Replacement of administration sets^a, needleless systems, and parenteral fluids
- A. Administration sets
 1. Replace administration sets, including secondary sets and add-on devices, no more frequently than at 72-hour intervals, unless catheter-related infection is suspected or documented.^{23,149–151} **Category IA**
 2. Replace tubing used to administer blood, blood products, or lipid emulsions (those combined with amino acids and glucose in a 3-in-1 admixture or infused separately) within 24 hours of initiating the infusion.^{158,226–229} **Category IB**. If the solution contains only dextrose and amino acids, the administration set does not need to be replaced more frequently than every 72 hours.²²⁶ **Category II**
 3. Replace tubing used to administer propofol infusions every 6 or 12 hours, depending on its use, per the manufacturer's recommendation.²³⁰ **Category IA**
 - B. Needleless intravascular devices
 1. Change the needleless components at least as frequently as the administration set.^{160–162,164–167} **Category II**
 2. Change caps no more frequently than every 72 hours or according to manufacturers' recommendations.^{160,162,165,166} **Category II**
3. Ensure that all components of the system are compatible to minimize leaks and breaks in the system.¹⁶³ **Category II**
 4. Minimize contamination risk by wiping the access port with an appropriate antiseptic and accessing the port only with sterile devices.^{162,163,165} **Category IB**
- C. Parenteral fluids
1. Complete the infusion of lipid-containing solutions (eg, 3-in-1 solutions) within 24 hours of hanging the solution.^{156–158,226,229} **Category IB**
 2. Complete the infusion of lipid emulsions alone within 12 hours of hanging the emulsion. If volume considerations require more time, the infusion should be completed within 24 hours.^{156–158} **Category IB**
 3. Complete infusions of blood or other blood products within 4 hours of hanging the blood.^{231–234} **Category II**
 4. No recommendation can be made for the hang time of other parenteral fluids. **Unresolved issue**
- X. IV-injection ports
- A. Clean injection ports with 70% alcohol or an iodophor before accessing the system.^{164,235,236} **Category IA**
 - B. Cap all stopcocks when not in use.²³⁵ **Category IB**
- XI. Preparation and quality control of IV admixtures
- A. Admix all routine parenteral fluids in the pharmacy in a laminar-flow hood using aseptic technique.^{237,238} **Category IB**
 - B. Do not use any container of parenteral fluid that has visible turbidity, leaks, cracks, or particulate matter or if the manufacturer's expiration date has passed.²³⁷ **Category IB**
 - C. Use single-dose vials for parenteral additives or medications when possible.^{237,239} **Category II**
 - D. Do not combine the leftover content of single-use vials for later use.^{237,239} **Category IA**
 - E. If multidose vials are used
 1. Refrigerate multidose vials after they are opened if recommended by the manufacturer. **Category II**
 2. Cleanse the access diaphragm of multidose vials with 70% alcohol before inserting a device into the vial.²³⁶ **Category IA**
 3. Use a sterile device to access a multidose vial and avoid touch contamination of the device before penetrating the access diaphragm.^{235,240} **Category IA**
 4. Discard multidose vial if sterility is compromised.^{235,240} **Category IA**
- XII. In-line filters
- Do not use filters routinely for infection-control purposes.^{80,241} **Category IA**
- XIII. IV-therapy personnel
- Designate trained personnel for the insertion

^aAdministration sets include the area from the spike of tubing entering the fluid container to the hub of the vascular access device. However, a short extension tube might be connected to the catheter and might be considered a portion of the catheter to facilitate aseptic technique when changing administration sets.

and maintenance of intravascular catheters.^{46,47,210,242} **Category IA**

XIV. Prophylactic antimicrobials

Do not administer intranasal or systemic antimicrobial prophylaxis routinely before insertion or during use of an intravascular catheter to prevent catheter colonization or BSI.^{97,98,108,243} **Category IA**

PERIPHERAL VENOUS CATHETERS, INCLUDING MIDLINE CATHETERS, IN ADULT AND PEDIATRIC PATIENTS

I. Selection of peripheral catheter

A. Select catheters on the basis of the intended purpose and duration of use, known complications (eg, phlebitis and infiltration), and experience of individual catheter operators.^{67,68,244} **Category IB**

B. Avoid the use of steel needles for the administration of fluids and medication that might cause tissue necrosis if extravasation occurs.^{67,68} **Category IA**

C. Use a midline catheter or PICC when the duration of IV therapy will likely exceed 6 days.²⁴⁴ **Category IB**

II. Selection of peripheral-catheter insertion site

A. In adults, use an upper- instead of a lower-extremity site for catheter insertion. Replace a catheter inserted in a lower-extremity site to an upper-extremity site as soon as possible.^{67,245} **Category IA**

B. In pediatric patients, the hand, the dorsum of the foot, or the scalp can be used as the catheter insertion site. **Category II**

C. Replacement of catheter

1. Evaluate the catheter insertion site daily, by palpation through the dressing to discern tenderness and by inspection if a transparent dressing is in use. Gauze and opaque dressings should not be removed if the patient has no clinical signs of infection. If the patient has local tenderness or other signs of possible CRBSI, an opaque dressing should be removed and the site inspected visually. **Category II**

2. Remove peripheral venous catheters if the patient develops signs of phlebitis (eg, warmth, tenderness, erythema, and palpable venous cord), infection, or a malfunctioning catheter.⁶⁶ **Category IB**

3. In adults, replace short, peripheral venous catheters at least 72–96 hours to reduce the risk for phlebitis. If sites for venous access are limited and no evidence of phlebitis or infection is present, peripheral venous catheters can be left in place for longer periods, although the patient and the insertion sites should be closely monitored.^{66,128,247} **Category IB**

4. Do not routinely replace midline catheters to reduce the risk for infection.¹³¹ **Category IB**

5. In pediatric patients, leave peripheral venous catheters in place until IV therapy is completed, unless a complication (eg, phlebitis and infiltration) occurs.^{174,175,222,223} **Category IB**

III. Catheter and catheter-site care

Do not routinely apply prophylactic topical antimicrobial or antiseptic ointment or cream to the insertion site of peripheral venous catheters.^{107,213} **Category IA**

CVCs, INCLUDING PICCs, HEMODIALYSIS, AND PULMONARY ARTERY CATHETERS, IN ADULT AND PEDIATRIC PATIENTS

I. Surveillance

A. Conduct surveillance in ICUs and other patient populations to determine CRBSI rates, monitor trends in those rates, and assist in identifying lapses in infection-control practices.^{3,12,16,247–250} **Category IA**

B. Express ICU data as the number of catheter-associated BSIs per 1,000 catheter-days for both adults and children and stratify by birth weight categories for neonatal ICUs to facilitate comparisons with national data in comparable patient populations and health-care settings.^{3,12,16,247–250} **Category IB**

C. Investigate events leading to unexpected life-threatening or fatal outcomes. This includes any process variation for which a recurrence would likely present an adverse outcome.¹³ **Category IC**

II. General principles

A. Use a CVC with the minimum number of ports or lumens essential for the management of the patient.^{251–254} **Category IB**

B. Use an antimicrobial or antiseptic-impregnated CVC in adults whose catheter is expected to remain in place >5 days if, after implementing a comprehensive strategy to reduce rates of CRBSI, the CRBSI rate remains above the goal set by the individual institution based on benchmark rates (Table 2) and local factors. The comprehensive strategy should include the following three components: educating persons who insert and maintain catheters, use of maximal sterile barrier precautions, and a 2% chlorhexidine preparation for skin antiseptics during CVC insertion.^{84–86,90,91,255} **Category IB**

C. No recommendation can be made for the use of impregnated catheters in children. **Unresolved issue**

D. Designate personnel who have been trained and exhibit competency in the insertion of catheters to supervise trainees who perform catheter insertion.^{39,43,46,182,187,188} **Category IA**

E. Use totally implantable access devices for patients who require long-term, intermittent vascular access. For patients requiring frequent or continuous access, a PICC or

- tunneled CVC is preferable.^{256,257} **Category II**
- F. Use a cuffed CVC for dialysis if the period of temporary access is anticipated to be prolonged (eg, >3 weeks).^{144,258} **Category IB**
 - G. Use a fistula or graft instead of a CVC for permanent access for dialysis.¹⁴² **Category IB**
 - H. Do not use hemodialysis catheters for blood drawing or applications other than hemodialysis except during dialysis or under emergency circumstances. **Category II**
 - I. Use povidone-iodine antiseptic ointment at the hemodialysis catheter exit site after catheter insertion and at the end of each dialysis session only if this ointment does not interact with the material of the hemodialysis catheter per manufacturer's recommendation.^{103,114,144} **Category II**
- III. Selection of catheter insertion site
- A. Weigh the risk and benefits of placing a device at a recommended site to reduce infectious complications against the risk for mechanical complications (eg, pneumothorax, subclavian artery puncture, subclavian vein laceration, subclavian vein stenosis, hemothorax, thrombosis, air embolism, and catheter misplacement).^{22,55,59,218} **Category IA**
 - B. Use a subclavian site (rather than a jugular or a femoral site) in adult patients to minimize infection risk for nontunneled CVC placement.^{22,55,59,60} **Category IA**
 - C. No recommendation can be made for a preferred site of insertion to minimize infection risk for a tunneled CVC.^{61–63} **Unresolved issue**
 - D. Place catheters used for hemodialysis and pheresis in a jugular or femoral vein rather than a subclavian vein to avoid venous stenosis if catheter access is needed.^{259–263} **Category IA**
- IV. Maximal sterile barrier precautions during catheter insertion
- A. Use aseptic technique including the use of a cap, mask, sterile gown, sterile gloves, and a large sterile sheet, for the insertion of CVCs (including PICCS) or guidewire exchange.^{22,71} **Category IA**
 - B. Use a sterile sleeve to protect pulmonary artery catheters during insertion.¹⁴⁸ **Category IB**
- V. Replacement of catheter
- A. Do not routinely replace CVCs, PICCs, hemodialysis catheters, or pulmonary artery catheters to prevent catheter-related infections.^{132,134,135} **Category IB**
 - B. Do not remove CVCs or PICCs on the basis of fever alone. Use clinical judgment regarding the appropriateness of removing the catheter if infection is evidenced elsewhere or if a noninfectious cause of fever is suspected.^{224,264} **Category II**
- C. Guidewire exchange
1. Do not use guidewire exchanges routinely for nontunneled catheters to prevent infection.^{135,265} **Category IB**
 2. Use a guidewire exchange to replace a malfunctioning nontunneled catheter if no evidence of infection is present.^{135,265} **Category IB**
 3. Use a new set of sterile gloves before handling the new catheter when guidewire exchanges are performed.^{22,71} **Category II**
- VI. Catheter and catheter-site care
- A. General measures

Designate one port exclusively for hyperalimentation if a multilumen catheter is used to administer parenteral nutrition.²⁶⁶ **Category II**
 - B. Antibiotic lock solutions

Do not routinely use antibiotic lock solutions to prevent CRBSI. Use prophylactic antibiotic lock solution only in special circumstances (eg, in treating a patient with a long-term cuffed or tunneled catheter or port who has a history of multiple CRBSIs despite optimal maximal adherence to aseptic technique).^{115,116,267,268} **Category II**
 - C. Catheter-site dressing regimens
 1. Replace the catheter-site dressing when it becomes damp, loosened, or soiled or when inspection of the site is necessary.^{65,146,211} **Category IA**
 2. Replace dressings used on short-term CVC sites every 2 days for gauze dressings and at least every 7 days for transparent dressings, except in those pediatric patients in which the risk for dislodging the catheter outweighs the benefit of changing the dressing.²¹¹ **Category IB**
 3. Replace dressings used on tunneled or implanted CVC sites no more than once per week, until the insertion site has healed.²¹¹ **Category IB**
 4. No recommendation can be made regarding the necessity for any dressing on well-healed exit sites of long-term cuffed and tunneled CVCs. **Unresolved issue**
 - D. No recommendation can be made for the use of chlorhexidine sponge dressings to reduce the incidence of infection. **Unresolved issue**
 - E. Do not use chlorhexidine sponge dressings in neonates aged <7 days or of gestational age <26 weeks.¹⁸¹ **Category II**
 - F. No recommendation can be made for the use of sutureless securement devices. **Unresolved issue**
 - G. Ensure that catheter-site care is compatible with the catheter material.^{109,110} **Category IB**
 - H. Use a sterile sleeve for all pulmonary artery catheters.¹⁴⁸ **Category IB**

ADDITIONAL RECOMMENDATIONS FOR
PERIPHERAL ARTERIAL CATHETERS AND
PRESSURE MONITORING DEVICES FOR ADULT
AND PEDIATRIC PATIENTS

- I. Selection of pressure monitoring system
Use disposable, rather than reusable, transducer assemblies when possible.^{269–273} **Category IB**
- II. Replacement of catheter and pressure monitoring system
 - A. Do not routinely replace peripheral arterial catheters to prevent catheter-related infections.^{132,147,221,274} **Category II**
 - B. Replace disposable or reusable transducers at 96-hour intervals. Replace other components of the system (including the tubing, continuous-flush device, and flush solution) at the time the transducer is replaced.^{22,270} **Category IB**
- III. Care of pressure monitoring systems
 - A. General measures
 1. Keep all components of the pressure monitoring system (including calibration devices and flush solution) sterile.^{269,275–277} **Category IA**
 2. Minimize the number of manipulations of and entries into the pressure monitoring system. Use a closed-flush system (ie, continuous flush), rather than an open system (ie, one that requires a syringe and stopcock), to maintain the patency of the pressure monitoring catheters.^{272,278} **Category II**
 3. When the pressure monitoring system is accessed through a diaphragm rather than a stopcock, wipe the diaphragm with an appropriate antiseptic before accessing the system.²⁷² **Category IA**
 4. Do not administer dextrose-containing solutions or parenteral nutrition fluids through the pressure monitoring circuit.^{272,279,280} **Category IA**
 - B. Sterilization or disinfection of pressure monitoring systems
 1. Use disposable transducers.^{272,279–282} **Category IB**
 2. Sterilize reusable transducers according to the manufacturers' instructions if the use of disposable transducers is not feasible.^{272,279–282} **Category IA**

RECOMMENDATIONS FOR UMBILICAL
CATHETERS

- I. Replacement of catheters
 - A. Remove and do not replace umbilical artery catheters if any signs of CRBSI, vascular insufficiency, or thrombosis are present.²⁸³ **Category II**
 - B. Remove and do not replace umbilical venous catheters if any signs of CRBSI or thrombosis are present.²⁸³ **Category II**
 - C. No recommendation can be made for treating through an umbilical venous catheter suspected of being infected. **Unresolved issue**
- D. Replace umbilical venous catheters only if the catheter malfunctions. **Category II**
- II. Catheter-site care
 - A. Cleanse the umbilical insertion site with an antiseptic before catheter insertion. Avoid tincture of iodine because of the potential effect on the neonatal thyroid. Other iodine-containing products (eg, povidone-iodine) can be used.^{175,177,178,284,285} **Category IB**
 - B. Do not use topical antibiotic ointment or creams on umbilical catheter insertion sites because of the potential to promote fungal infections and antimicrobial resistance.^{107,213} **Category IA**
 - C. Add low doses of heparin (0.25–1.0 F/ml) to the fluid infused through umbilical arterial catheters.^{286–288} **Category IB**
 - D. Remove umbilical catheters as soon as possible when no longer needed or when any sign of vascular insufficiency to the lower extremities is observed. Optimally, umbilical artery catheters should not be left in place >5 days.^{283,289} **Category II**
 - E. Umbilical venous catheters should be removed as soon as possible when no longer needed but can be used up to 14 days if managed aseptically.^{290,291} **Category II**

REFERENCES

1. Pearson ML. Guideline for prevention of intravascular device-related infections. Part I. Intravascular device-related infections: an overview. The Hospital Infection Control Practices Advisory Committee. *Am J Infect Control*. 1996;24:262–277
2. Mermel LA. Prevention of intravascular catheter-related infections. *Ann Intern Med*. 2000;132:391–402
3. CDC. National Nosocomial Infections Surveillance (NNIS) System report, data summary from October 1986–April 1998, issued June 1998. *Am J Infect Control*. 1998;26:522–533
4. Digiovine B, Chenoweth C, Watts C, Higgins M. The attributable mortality and costs of primary nosocomial bloodstream infections in the intensive care unit. *Am J Respir Crit Care Med*. 1999;160:976–981
5. Rello J, Ochagavia A, Sabanes E, et al. Evaluation of outcome of intravenous catheter-related infections in critically ill patients. *Am J Respir Crit Care Med*. 2000;162:1027–1030
6. Soufir L, Timsit JF, Mahe C, Carlet J, Regnier B, Chevret S. Attributable morbidity and mortality of catheter-related septicemia in critically ill patients: a matched, risk-adjusted, cohort study. *Infect Control Hosp Epidemiol*. 1999;20:396–401
7. Collignon PJ. Intravascular catheter associated sepsis: a common problem. The Australian Study on Intravascular Catheter Associated Sepsis. *Med J Aust*. 1994;161:374–378
8. Pittet D, Tarara D, Wenzel RP. Nosocomial bloodstream infection in critically ill patients. Excess length of stay, extra costs, and attributable mortality. *JAMA*. 1994;271:1598–1601
9. Dimick JB, Pelz RK, Consunji R, Swoboda SM, Hendrix CW, Lipsett PA. Increased resource use associated with catheter-related bloodstream infection in the surgical intensive care unit. *Arch Surg*. 2001;136:229–234
10. Mermel LA. Correction: catheter related bloodstream-infections. *Ann Intern Med*. 2000;133:395
11. Kluger DM, Maki DG. The relative risk of intravascular device related bloodstream infections in adults [abstract]. In: *Abstracts of the 39th Interscience Conference on Antimicrobial Agents and Chemotherapy*. San Francisco, CA: American Society for Microbiology; 1999:514
12. CDC. National Nosocomial Infections Surveillance (NNIS) System report, data summary from January 1990–May 1999, issued June 1999. *Am J Infect Control*. 1999;27:520–532
13. Joint Commission on the Accreditation of Healthcare Organizations. Accreditation manual for hospitals. In: Joint Commission on the Ac-

- creditation of Healthcare Organizations, ed. Chicago, IL: Joint Commission on the Accreditation of Healthcare Organizations; 1994: 121–140
14. CDC. National Nosocomial Infections Surveillance (NNIS) System report, data summary from January 1992–June 2001, issued August 2001. *Am J Infect Control.* 2001;6:404–421
 15. Schaberg DR, Culver DH, Gaynes RP. Major trends in the microbial etiology of nosocomial infection. *Am J Med.* 1991;91(suppl):S72–S75
 16. Banerjee SN, Emori TG, Culver DH, et al. Secular trends in nosocomial primary bloodstream infections in the United States, 1980–1989. National Nosocomial Infections Surveillance System. *Am J Med.* 1991; 91(suppl):S86–S89
 17. Pfaller MA, Jones RN, Messer SA, Edmond MB, Wenzel RP. National surveillance of nosocomial blood stream infection due to *Candida albicans*: frequency of occurrence and antifungal susceptibility in the SCOPE Program. *Diagn Microbiol Infect Dis.* 1998;31:327–332
 18. Pfaller MA, Jones RN, Messer SA, Edmond MB, Wenzel RP. National surveillance of nosocomial blood stream infection due to species of *Candida* other than *Candida albicans*: frequency of occurrence and antifungal susceptibility in the SCOPE Program. *Diagn Microbiol Infect Dis.* 1998;30:121–129
 19. Nguyen MH, Peacock JE Jr, Morris AJ, et al. The changing face of candidemia: emergence of non-*Candida albicans* species and antifungal resistance. *Am J Med.* 1996;100:617–623
 20. Fridkin SK, Gaynes RP. Antimicrobial resistance in intensive care units. *Clin Chest Med.* 1999;20:303–316
 21. Maki DG, Weise CE, Sarafin HW. A semiquantitative culture method for identifying intravenous-catheter-related infection. *N Engl J Med.* 1977;296:1305–1309
 22. Mermel LA, McCormick RD, Springman SR, Maki DG. The pathogenesis and epidemiology of catheter-related infection with pulmonary artery Swan-Ganz catheters: a prospective study utilizing molecular subtyping. *Am J Med.* 1991;91(suppl):S197–S205
 23. Sitges-Serra A, Linares J, Perez JL, Jaurrieta E, Lorente L. A randomized trial on the effect of tubing changes on hub contamination and catheter sepsis during parenteral nutrition. *Parenter Enter Nutr.* 1985; 9:322–325
 24. Linares J, Sitges-Serra A, Garau J, Perez JL, Martin R. Pathogenesis of catheter sepsis: a prospective study with quantitative and semiquantitative cultures of catheter hub and segments. *J Clin Microbiol.* 1985; 21:357–360
 25. Raad II, 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;168:400–407
 26. Maki DG. Infections associated with intravascular lines. In: Remington JS, ed. *Current Clinical Topics in Infectious Diseases.* New York, NY: McGraw-Hill; 1982:309–363
 27. Sheth NK, Franson TR, Rose HD, Buckmire FL, Cooper JA, Sohnle PG. Colonization of bacteria on polyvinyl chloride and Teflon intravascular catheters in hospitalized patients. *J Clin Microbiol.* 1983;18: 1061–1063
 28. Ashkenazi S, Weiss E, Drucker MM, Bodey GP. Bacterial adherence to intravenous catheters and needles and its influence by cannula type and bacterial surface hydrophobicity. *J Lab Clin Med.* 1986;107:136–140
 29. Locci R, Peters G, Pulverer G. Microbial colonization of prosthetic devices. IV. Scanning electron microscopy of intravenous catheters invaded by yeasts. *Zentralbl Bakteriell Mikrobiol Hyg [B].* 1981;173: 419–424
 30. Locci R, Peters G, Pulverer G. Microbial colonization of prosthetic devices. I. Microtopographical characteristics of intravenous catheters as detected by scanning electron microscopy. *Zentralbl Bakteriell Mikrobiol Hyg [B].* 1981;173:285–292
 31. Nachmani GH, Lessin LS, Motomiya T, Jensen WN, Bodey GP. Scanning electron microscopy of thrombogenesis on vascular catheter surfaces. *N Engl J Med.* 1972;286:139–140
 32. Stillman RM, Soliman F, Garcia L, Sawyer PN. Etiology of catheter-associated sepsis. Correlation with thrombogenicity. *Arch Surg.* 1977; 112:1497–1499
 33. Herrmann M, Lai QJ, Albrecht RM, Mosher DF, Proctor RA. Adhesion of *Staphylococcus aureus* to surface-bound platelets: role of fibrinogen/fibrin and platelet integrins. *J Infect Dis.* 1993;167:312–322
 34. Herrmann M, Suchard SJ, Boxer LA, Waldvogel FA, Lew PD. Thrombospondin binds to *Staphylococcus aureus* and promotes staphylococcal adherence to surfaces. *Infect Immun.* 1991;59:279–288
 35. Ludwicka A, Uhlenbruck G, Peters G, et al. Investigation on extracellular slime substance produced by *Staphylococcus epidermidis*. *Zentralbl Bakteriell Mikrobiol Hyg.* 1984;258:256–267
 36. Gray ED, Peters G, Versteegen M, Regelman WE. Effect of extracellular slime substance from *Staphylococcus epidermidis* on the human cellular immune response. *Lancet.* 1984;1:365–367
 37. Farber BF, Kaplan MH, Clogston AG. *Staphylococcus epidermidis* extracted slime inhibits the antimicrobial action of glycopeptide antibiotics. *J Infect Dis.* 1990;161:37–40
 38. Branchini ML, Pfaller MA, Rhine-Chalberg J, Frempong T, Isenberg HD. Genotypic variation and slime production among blood and catheter isolates of *Candida parapsilosis*. *J Clin Microbiol.* 1994;32: 452–456
 39. Sherertz RJ, Ely EW, Westbrook DM, et al. Education of physicians-in-training can decrease the risk for vascular catheter infection. *Ann Intern Med.* 2000;132:641–648
 40. Ryan JA Jr, Abel RM, Abbott WM, et al. Catheter complications in total parenteral nutrition: a prospective study of 200 consecutive patients. *N Engl J Med.* 1974;290:757–761
 41. Sanders RA, Sheldon GF. Septic complications of total parenteral nutrition: a five year experience. *Am J Surg.* 1976;132:214–220
 42. Murphy LM, Lipman TO. Central venous catheter care in parenteral nutrition: a review. *Parenter Enter Nutr.* 1987;11:190–201
 43. Eggimann P, Harbarth S, Constantin MN, Touveneau S, Chevrolet JC, Pittet D. Impact of a prevention strategy targeted at vascular-access care on incidence of infections acquired in intensive care. *Lancet.* 2000;355:1864–1868
 44. Armstrong CW, Mayhall CG, Miller KB, et al. Prospective study of catheter replacement and other risk factors for infection of hyperalimentation catheters. *J Infect Dis.* 1986;154:808–816
 45. Nehme AE. Nutritional support of the hospitalized patient: the team concept. *JAMA.* 1980;243:1906–1908
 46. Soifer NE, Borzak S, Edlin BR, Weinstein RA. Prevention of peripheral venous catheter complications with an intravenous therapy team: a randomized controlled trial. *Arch Intern Med.* 1998;158:473–477
 47. Tomford JW, Hershey CO. The IV therapy team: impact on patient care and costs of hospitalization. *NITA.* 1985;8:387–389
 48. Fridkin SK, Pear SM, Williamson TH, Galgiani JN, Jarvis WR. The role of understaffing in central venous catheter-associated bloodstream infections. *Infect Control Hosp Epidemiol.* 1996;17:150–158
 49. Bansmer G, Keith D, Tesluk H. Complications following use of indwelling catheters of inferior vena cava. *JAMA.* 1958;167:1606–1611
 50. Crane C. Venous interruption of septic thrombophlebitis. *N Engl J Med.* 1960;262:947–951
 51. Indar R. The dangers of indwelling polyethylene cannulae in deep veins. *Lancet.* 1959;1:284–286
 52. Maki DG, Mermel LA. Infections due to infusion therapy. In: Bennett JV, Brachman PS, eds. *Hospital Infections.* 4th ed. Philadelphia, PA: Lippencott-Raven; 1998:689–724
 53. 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;158:81–87
 54. Richet H, Hubert B, Nitemberg G, et al. Prospective multicenter study of vascular-catheter-related complications and risk factors for positive central-catheter cultures in intensive care unit patients. *J Clin Microbiol.* 1990;28:2520–2525
 55. Goetz AM, Wagener MM, Miller JM, Muder RR. Risk of infection due to central venous catheters: effect of site of placement and catheter type. *Infect Control Hosp Epidemiol.* 1998;19:842–845
 56. Joynnt GM, Kew J, Gomersall CD, Leung VY, Liu EK. Deep venous thrombosis caused by femoral venous catheters in critically ill adult patients. *Chest.* 2000;117:178–183
 57. Mian NZ, Bayly R, Schreck DM, Besserman EB, Richmand D. Incidence of deep venous thrombosis associated with femoral venous catheterization. *Acad Emerg Med.* 1997;4:1118–1121
 58. 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;25:1986–1989
 59. Trottier SJ, Veremakis C, O'Brien J, Auer AI. Femoral deep vein thrombosis associated with central venous catheterization: results from a prospective, randomized trial. *Crit Care Med.* 1995;23:52–59
 60. 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;286:700–707
 61. Venkataraman ST, Thompson AE, Orr RA. Femoral vascular catheterization in critically ill infants and children. *Clin Pediatr.* 1997;36: 311–319
 62. Stenzel JP, Green TP, Fuhrman BP, Carlson PE, Marchessault RP. Percutaneous femoral venous catheterizations: a prospective study of complications. *J Pediatr.* 1989;114:411–415

63. Goldstein AM, Weber JM, Sheridan RL. Femoral venous access is safe in burned children: an analysis of 224 catheters. *J Pediatr.* 1997;130:442–446
64. 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;24:2053–2058
65. Maki DG, Ringer M. Evaluation of dressing regimens for prevention of infection with peripheral intravenous catheters: gauze, a transparent polyurethane dressing, and an iodophor-transparent dressing. *JAMA.* 1987;258:2396–2403
66. Maki DG, Ringer M. Risk factors for infusion-related phlebitis with small peripheral venous catheters: a randomized controlled trial. *Ann Intern Med.* 1991;114:845–854
67. Band JD, Maki DG. Steel needles used for intravenous therapy: morbidity in patients with hematologic malignancy. *Arch Intern Med.* 1980;140:31–34
68. Tully JL, Friedland GH, Baldini LM, Goldmann DA. Complications of intravenous therapy with steel needles and Teflon catheters: a comparative study. *Am J Med.* 1981;70:702–706
69. Pittet D, Hugonnet S, Harbath S, et al. Effectiveness of a hospital-wide programme to improve compliance with hand hygiene. *Lancet.* 2000;356:1307–1309
70. Larson EL, Rackoff WR, Weiman M, et al. APIC guideline for hand-washing and hand antisepsis in health care settings. *Am J Infect Control.* 1995;23:251–269
71. 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;15:231–238
72. Clemence MA, Walker D, Farr BM. Central venous catheter practices: results of a survey. *Am J Infect Control.* 1995;23:5–12
73. 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;338:339–343
74. Humar A, Ostromecki A, Dierenfeld J, et al. Prospective randomized trial of 10% povidone-iodine versus 0.5% tincture of chlorhexidine as cutaneous antiseptics for prevention of central venous catheter infection. *Clin Infect Dis.* 2000;31:1001–1007
75. Garland JS, Buck RK, Maloney P, et al. Comparison of 10% povidone-iodine and 0.5% chlorhexidine gluconate for the prevention of peripheral intravenous catheter colonization in neonates: a prospective trial. *Pediatr Infect Dis J.* 1995;14:510–516
76. Hoffmann KK, Weber DJ, Samsa GP, Rutala WA. Transparent polyurethane film as an intravenous catheter dressing: a meta-analysis of the infection risks. *JAMA.* 1992;267:2072–2076
77. Maki DG, Mermel LA, Klugar D, et al. The efficacy of a chlorhexidine impregnated sponge (Biopatch) for the prevention of intravascular catheter-related infection— a prospective randomized controlled multicenter study [abstract]. Presented at the Interscience Conference on Antimicrobial Agents and Chemotherapy. Toronto, Ontario, Canada: American Society for Microbiology, 2000
78. Yamamoto AJ, Solomon JA, Soulen MC, et al. Sutureless securement device reduces complications of peripherally inserted central venous catheters. *J Vasc Interv Radiol.* 2002;13:77–81
79. Rusho WJ, Bair JN. Effect of filtration on complications of postoperative intravenous therapy. *Am J Hosp Pharm.* 1979;36:1355–1356
80. Maddox RR, John JF Jr, Brown LL, Smith CE. Effect of inline filtration on postinfusion phlebitis. *Clin Pharm.* 1983;2:58–61
81. Turco SJ, Davis NM. Particulate matter in intravenous infusion fluids—phase 3. *Am J Hosp Pharm.* 1973;30:611–613
82. Baumgartner TG, Schmidt GL, Thakker KM, et al. Bacterial endotoxin retention by inline intravenous filters. *Am J Hosp Pharm.* 1986;43:681–684
83. Butler DL, Munson JM, DeLuca PP. Effect of inline filtration on the potency of low-dose drugs. *Am J Hosp Pharm.* 1980;37:935–941
84. Raad II, 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. The Texas Medical Center Catheter Study Group. *Ann Intern Med.* 1997;127:267–274
85. 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;281:261–267
86. 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;127:257–266
87. Raad II, Darouiche R, Hachem R, Mansouri M, Bodey GP. The broad-spectrum activity and efficacy of catheters coated with minocycline and rifampin. *J Infect Dis.* 1996;173:418–424
88. Bassetti S, Hu J, D'Agostino RB Jr, Sherertz RJ. Prolonged antimicrobial activity of a catheter containing chlorhexidine-silver sulfadiazine extends protection against catheter infections in vivo. *Antimicrob Agents Chemother.* 2001;45:1535–1538
89. Oda T, Hamasaki J, Kanda N, Mikami K. Anaphylactic shock induced by an antiseptic-coated central venous catheter. *Anesthesiology.* 1997;87:1242–1244
90. Veenstra DL, Saint S, Sullivan SD. Cost-effectiveness of antiseptic-impregnated central venous catheters for the prevention of catheter-related bloodstream infection. *JAMA.* 1999;282:554–560
91. Darouiche RO, Raad II, Heard SO, et al. A comparison of two antimicrobial-impregnated central venous catheters. Catheter Study Group. *N Engl J Med.* 1999;340:1–8
92. Institute of Medicine. *To Err Is Human: Building a Safer Health System.* Washington, DC: National Academy Press; 2000
93. Maki DG, Cobb L, Garman JK, Shapiro JM, Ringer M, Helgeson RB. An attachable silver-impregnated cuff for prevention of infection with central venous catheters: a prospective randomized multicenter trial. *Am J Med.* 1988;85:307–314
94. Dahlberg PJ, Agger WA, Singer JR, et al. Subclavian hemodialysis catheter infections: a prospective, randomized trial of an attachable silver-impregnated cuff for prevention of catheter-related infections. *Infect Control Hosp Epidemiol.* 1995;16:506–511
95. Groeger JS, Lucas AB, Coit D, et al. A prospective, randomized evaluation of the effect of silver impregnated subcutaneous cuffs for preventing tunneled chronic venous access catheter infections in cancer patients. *Ann Surg.* 1993;218:206–210
96. Bonawitz SC, Hammell EJ, Kirkpatrick JR. Prevention of central venous catheter sepsis: a prospective randomized trial. *Am Surg.* 1991;57:618–623
97. McKee R, Dunsmuir R, Whitby M, Garden OJ. Does antibiotic prophylaxis at the time of catheter insertion reduce the incidence of catheter-related sepsis in intravenous nutrition? *J Hosp Infect.* 1985;6:419–425
98. Ranson MR, Oppenheim BA, Jackson A, Kamthan AG, Scarffe JH. Double-blind placebo controlled study of vancomycin prophylaxis for central venous catheter insertion in cancer patients. *J Hosp Infect.* 1990;15:95–102
99. Ljungman P, Hagglund H, Bjorkstrand B, Lonnqvist B, Ringden O. Operative teicoplanin for prevention of gram-positive infections in neutropenic patients with indwelling central venous catheters: a randomized, controlled study. *Support Care Cancer.* 1997;5:485–488
100. Kacica MA, Horgan MJ, Ochoa L, Sandler R, Lepow ML, Venezia RA. Prevention of gram-positive sepsis in neonates weighing less than 1500 g. *J Pediatr.* 1994;125:253–258
101. Spafford PS, Sinkin RA, Cox C, Reubens L, Powell KR. Prevention of central venous catheter-related coagulase-negative staphylococcal sepsis in neonates. *J Pediatr.* 1994;125:259–263
102. CDC. Recommendations for preventing the spread of vancomycin resistance. Recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC). *MMWR Recomm Rep.* 1995;44(No. RR-12):1–13
103. Levin A, Mason AJ, Jindal KK, Fong IW, Goldstein MB. Prevention of hemodialysis subclavian vein catheter infections by topical povidone-iodine. *Kidney Int.* 1991;40:934–938
104. Casewell MW. The nose: an underestimated source of *Staphylococcus aureus* causing wound infection. *J Hosp Infect.* 1998;40(suppl):S3–S11
105. Hill RL, Fisher AP, Ware RJ, Wilson S, Casewell MW. Mupirocin for the reduction of colonization of internal jugular cannulae—a randomized controlled trial. *J Hosp Infect.* 1990;15:311–321
106. Sesso R, Barbosa D, Leme IL, et al. *Staphylococcus aureus* prophylaxis in hemodialysis patients using central venous catheter: effect of mupirocin ointment. *J Am Soc Nephrol.* 1998;9:1085–1092
107. Zakrzewska-Bode A, Muyltjens 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;31:189–193
108. Miller MA, Dascal A, Portnoy J, Mendelson J. Development of mupirocin resistance among methicillin-resistant *Staphylococcus aureus* after widespread use of nasal mupirocin ointment. *Infect Control Hosp Epidemiol.* 1996;17:811–813
109. Rao SP, Oreopoulos DG. Unusual complications of a polyurethane PD catheter. *Perit Dial Int.* 1997;17:410–412
110. Riu S, Ruiz CG, Martinez-Vea A, Peralta C, Oliver JA. Spontaneous rupture of polyurethane peritoneal catheter: a possible deleterious

- effect of mupirocin ointment. *Nephrol Dial Transplant*. 1998;13:1870-1871
111. von Eiff C, Becker K, Machka K, Stammer H, Peters G. Nasal carriage as a source of *Staphylococcus aureus* bacteremia. *N Engl J Med*. 2001;344:11-16
 112. Zinner SH, Denny-Brown BC, Braun P, Burke JP, Toala P, Kass EH. Risk of infection with intravenous indwelling catheters: effect of application of antibiotic ointment. *J Infect Dis*. 1969;120:616-619
 113. Norden CW. Application of antibiotic ointment to the site of venous catheterization—a controlled trial. *J Infect Dis*. 1969;120:611-615
 114. Maki DG, Band JD. A comparative study of polyantibiotic and iodophor ointments in prevention of vascular catheter-related infection. *Am J Med*. 1981;70:739-744
 115. 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;18:1269-1278
 116. Carratala J, Niubo J, Fernandez-Sevilla A, et al. Randomized, double-blind trial of an antibiotic-lock technique for prevention of gram-positive central venous catheter-related infection in neutropenic patients with cancer. *Antimicrob Agents Chemother*. 1999;43:2200-2204
 117. Schwartz C, Henrickson KJ, Roghmann K, Powell K. Prevention of bacteremia attributed to luminal colonization of tunneled central venous catheters with vancomycin-susceptible organisms. *J Clin Oncol*. 1990;8:1591-1597
 118. Rackoff WR, Weiman M, Jakobowski D, et al. A randomized, controlled trial of the efficacy of a heparin and vancomycin solution in preventing central venous catheter infections in children. *J Pediatr*. 1995;127:147-151
 119. Raad II, Buzaid A, Rhyne J, et al. Minocycline and ethylene-diaminetetraacetate for the prevention of recurrent vascular catheter infections. *Clin Infect Dis*. 1997;25:149-151
 120. Raad II, Luna M, Khalil SA, Costerton JW, Lam C, Bodey GP. The relationship between the thrombotic and infectious complications of central venous catheters. *JAMA*. 1994;271:1014-1016
 121. 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;114:207-213
 122. Randolph AG, Cook DJ, Gonzales CA, Andrew M. Benefit of heparin in central venous and pulmonary artery catheters: a meta-analysis of randomized controlled trials. *Chest*. 1998;113:165-171
 123. Mermel LA, Stolz SM, Maki DG. Surface antimicrobial activity of heparin-bonded and antiseptic-impregnated vascular catheters. *J Infect Dis*. 1993;167:920-924
 124. Pierce CM, Wade A, Mok Q. Heparin-bonded central venous lines reduce thrombotic and infective complications in critically ill children. *Intensive Care Med*. 2000;26:967-972
 125. Bern MM, Lokich JJ, Wallach SR, et al. Very low doses of warfarin can prevent thrombosis in central venous catheters: a randomized prospective trial. *Ann Intern Med*. 1990;112:423-428
 126. Boraks P, Seale J, Price J, et al. Prevention of central venous catheter associated thrombosis using minidose warfarin in patients with haematological malignancies. *Br J Haematol*. 1998;101:483-486
 127. Collin J, Collin C. Infusion thrombophlebitis. *Lancet*. 1975;2:458
 128. Lai KK. Safety of prolonging peripheral cannula and i.v. tubing use from 72 hours to 96 hours. *Am J Infect Control*. 1998;26:66-70
 129. Fontaine PJ. Performance of a new softening expanding midline catheter in home intravenous therapy patients. *J Intraven Nurs*. 1991;14:91-99
 130. Harwood IR, Greene LM, Kozakowski-Koch JA, Rasor JS. New peripherally inserted midline catheter: a better alternative for intravenous antibiotic therapy in patients with cystic fibrosis. *Pediatr Pulmonol*. 1992;12:233-239
 131. Mermel LA, Parenteau S, Tow SM. The risk of midline catheterization in hospitalized patients. A prospective study. *Ann Intern Med*. 1995;123:841-844
 132. 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;18:1073-1079
 133. Uldall PR, Merchant N, Woods F, Yarworski U, Vas S. Changing subclavian haemodialysis cannulas to reduce infection. *Lancet*. 1981;1:1373
 134. Cook D, Randolph A, Kernerman P, et al. Central venous catheter replacement strategies: a systematic review of the literature. *Crit Care Med*. 1997;25:1417-1424
 135. 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;327:1062-1068
 136. Robinson D, Suhocki P, Schwab SJ. Treatment of infected tunneled venous access hemodialysis catheters with guidewire exchange. *Kidney Int*. 1998;53:1792-1794
 137. Beathard GA. Management of bacteremia associated with tunneled-cuffed hemodialysis catheters. *J Am Soc Nephrol*. 1999;10:1045-1049
 138. Saad TF. Bacteremia associated with tunneled, cuffed hemodialysis catheters. *Am J Kidney Dis*. 1999;34:1114-1124
 139. Duszak R Jr, Haskal ZJ, Thomas-Hawkins C, et al. Replacement of failing tunneled hemodialysis catheters through pre-existing subcutaneous tunnels: a comparison of catheter function and infection rates for de novo placements and over-the-wire exchanges. *J Vasc Interv Radiol*. 1998;9:321-327
 140. Jaar BG, Hermann JA, Furth SL, Briggs W, Powe NR. Septicemia in diabetic hemodialysis patients: comparison of incidence, risk factors, and mortality with nondiabetic hemodialysis patients. *Am J Kidney Dis*. 2000;35:282-292
 141. Powe NR, Jaar B, Furth SL, Hermann J, Briggs W. Septicemia in dialysis patients: incidence, risk factors, and prognosis. *Kidney Int*. 1999;55:1081-1090
 142. Hoen B, Paul-Dauphin A, Hestin D, Kessler M. EPIBACDIAL: a multicenter prospective study of risk factors for bacteremia in chronic hemodialysis patients. *J Am Soc Nephrol*. 1998;9:869-976
 143. Tokars JL, Miller ER, Alter MJ, et al. National surveillance of dialysis-associated diseases in the United States, 1997. *Semin Dial*. 2000;13:75-85
 144. Foundation NK. III. NKF-K/DOQI Clinical practice guidelines for vascular access: update 2000. *Am J Kidney Dis*. 2001;37(suppl):S137-S181
 145. Mermel LA. Intravascular catheters impregnated with benzalkonium chloride. *J Antimicrob Chemother*. 1993;32:905-906
 146. 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;22:1729-1737
 147. Raad II, Umphrey J, Khan A, Truett LJ, Bodey GP. The duration of placement as a predictor of peripheral and pulmonary arterial catheter infections. *J Hosp Infect*. 1993;23:17-26
 148. Cohen Y, Fosse JP, Karoubi P, et al. The "hands-off" catheter and the prevention of systemic infections associated with pulmonary artery catheter: a prospective study. *Am J Respir Crit Care Med*. 1998;157:284-287
 149. Josephson A, Gombert ME, Sierra MF, Karanfil LV, Tansino GF. The relationship between intravenous fluid contamination and the frequency of tubing replacement. *Infect Control*. 1985;6:367-370
 150. Maki DG, Botticelli JT, LeRoy ML, Thielke TS. Prospective study of replacing administration sets for intravenous therapy at 48- vs 72-hour intervals: 72 hours is safe and cost-effective. *JAMA*. 1987;258:1777-1781
 151. Snyderman DR, Donnelly-Reidy M, Perry LK, Martin WJ. Intravenous tubing containing burettes can be safely changed at 72 hour intervals. *Infect Control*. 1987;8:113-116
 152. Hanna HA, Raad II. Blood products: a significant risk factor for long-term catheter-related bloodstream infections in cancer patients. *Infect Control Hosp Epidemiol*. 2001;22:165-166
 153. Raad II, Hanna HA, Awad A, et al. Optimal frequency of changing intravenous administration sets: is it safe to prolong use beyond 72 hours? *Infect Control Hosp Epidemiol*. 2001;22:136-139
 154. Saiman L, Ludington E, Dawson JD, et al. Risk factors for *Candida* species colonization of neonatal intensive care unit patients. *Pediatr Infect Dis J*. 2001;20:1119-1124
 155. Avila-Figueroa C, Goldmann DA, Richardson DK, Gray JE, Ferrari A, Freeman J. Intravenous lipid emulsions are the major determinant of coagulase-negative staphylococcal bacteremia in very low birth weight newborns. *Pediatr Infect Dis J*. 1998;17:10-17
 156. Crocker KS, Noga R, Filibeck DJ, Krey SH, Markovic M, Steffee WP. Microbial growth comparisons of five commercial parenteral lipid emulsions. *J Parenter Enteral Nutr*. 1984;8:391-395
 157. Jarvis WR, Highsmith AK. Bacterial growth and endotoxin production in lipid emulsion. *J Clin Microbiol*. 1984;19:17-20
 158. Melly MA, Meng HC, Schaffner W. Microbiol growth in lipid emulsions used in parenteral nutrition. *Arch Surg*. 1975;110:1479-1481
 159. Inoue Y, Nezu R, Matsuda H, et al. Prevention of catheter-related sepsis during parenteral nutrition: effect of a new connection device. *J Parenter Enteral Nutr*. 1992;16:581-585
 160. Arduino MJ, Bland LA, Danzig LE, McAllister SK, Aguero SM. Micro-

- biologic evaluation of needleless and needle-access devices. *Am J Infect Control*. 1997;25:377–380
161. Brown JD, Moss HA, Elliott TS. The potential for catheter microbial contamination from a needleless connector. *J Hosp Infect*. 1997;36:181–189
 162. 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;19:23–27
 163. Do AN, Ray BJ, Banerjee SN, et al. Bloodstream infection associated with needleless device use and the importance of infection-control practices in the home health care setting. *J Infect Dis*. 1999;179:442–448
 164. Luebke MA, Arduino MJ, Duda DL, et al. Comparison of the microbial barrier properties of a needleless and a conventional needle-based intravenous access system. *Am J Infect Control*. 1998;26:437–441
 165. 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;19:772–777
 166. Mendelson MH, Short LJ, Schechter CB, et al. Study of a needleless intermittent intravenous-access system for peripheral infusions: analysis of staff, patient, and institutional outcomes. *Infect Control Hosp Epidemiol*. 1998;19:401–406
 167. Seymour VM, Dhallu TS, Moss HA, Tebbs SE, Elliot TS. A prospective clinical study to investigate the microbial contamination of a needleless connector. *J Hosp Infect*. 2000;45:165–168
 168. Longfield RN, Smith LP, Longfield JN, Coberly J, Cruess D. Multiple-dose vials: persistence of bacterial contaminants and infection control implications. *Infect Control*. 1985;6:194–199
 169. Henry B, Plante-Jenkins C, Ostrowska K. An outbreak of *Serratia marcescens* associated with the anesthetic agent propofol. *Am J Infect Control*. 2001;29:312–315
 170. Grohskopf LA, Roth VR, Feikin DR, et al. *Serratia liquefaciens* bloodstream infections from contamination of epoetin alfa at a hemodialysis center. *N Engl J Med*. 2001;344:1491–1497
 171. CDC. National Nosocomial Infections Surveillance (NNIS) System report, data summary from April 1995–April 2000, issued June 2000. *Am J Infect Control*. 2000;28:429–435
 172. Richards MJ, Edwards JR, Culver DH, Gaynes RP. Nosocomial infections in pediatric intensive care units in the United States: National Nosocomial Infections Surveillance System. *Pediatrics*. 1999;103:103–109
 173. Richards MJ, Edwards JR, Culver DH, Gaynes RP. Nosocomial infections in medical intensive care units in the United States: National Nosocomial Infections Surveillance System. *Crit Care Med*. 1999;27:887–892
 174. Garland JS, Dunne WM Jr, Havens P, et al. Peripheral intravenous catheter complications in critically ill children: a prospective study. *Pediatrics*. 1992;89:1145–1150
 175. Garland JS, Nelson DB, Cheah TE, Hennes HH, Johnson TM. Infectious complications during peripheral intravenous therapy with Teflon catheters: a prospective study. *Pediatr Infect Dis J*. 1987;6:918–921
 176. Furfaro S, Gauthier M, Lacroix J, Nadeau D, Lafleur L, Mathews S. Arterial catheter-related infections in children: a 1-year cohort analysis. *Am J Dis Child*. 1991;145:1037–1043
 177. Krauss AN, Albert RF, Kannan MM. Contamination of umbilical catheters in the newborn infant. *J Pediatr*. 1970;77:965–969
 178. Landers S, Moise AA, Fraley JK, Smith EO, Baker CJ. Factors associated with umbilical catheter-related sepsis in neonates. *Am J Dis Child*. 1991;145:675–680
 179. Balagtas RC, Bell CE, Edwards LD, Levin S. Risk of local and systemic infections associated with umbilical vein catheterization: a prospective study in 86 newborn patients. *Pediatrics*. 1971;48:359–367
 180. Stenzel JP, Green TP, Fuhrman BP, Carlson PE, Marchessault RP. Percutaneous central venous catheterization in a pediatric intensive care unit: a survival analysis of complications. *Crit Care Med*. 1989;17:984–988
 181. Garland JS, Alex CP, Mueller CD, et al. A randomized trial comparing povidone-iodine to a chlorhexidine gluconate-impregnated dressing for prevention of central venous catheter infections in neonates. *Pediatrics*. 2001;107:1431–1436
 182. Davis D, O'Brien MA, Freemantle N, Wolf FM, Mazmanian P, Taylor-Vaisey A. Impact of formal continuing medical education: do conferences, workshops, rounds, and other traditional continuing education activities change physician behavior or health care outcomes? *JAMA*. 1999;282:867–874
 183. Conly JM, Hill S, Ross J, Lertzman J, Louie TJ. Handwashing practices in an intensive care unit: the effects of an educational program and its relationship to infection rates. *Am J Infect Control*. 1989;17:330–339
 184. East SA. Planning, implementation, and evaluation of a successful hospital-based peripherally inserted central catheter program. *J Intraven Nurs*. 1994;17:189–192
 185. Kyle KS, Myers JS. Peripherally inserted central catheters. Development of a hospital-based program. *J Intraven Nurs*. 1990;13:287–290
 186. BeVier PA, Rice CE. Initiating a pediatric peripherally inserted central catheter and midline catheter program. *J Intraven Nurs*. 1994;17:201–205
 187. Tomford JW, Hershey CO, McLaren CE, Porter DK, Cohen DI. Intravenous therapy team and peripheral venous catheter-associated complications: a prospective controlled study. *Arch Intern Med*. 1984;144:1191–1194
 188. Wenzel RP, Wentzel RP. The development of academic programs for quality assessment. *Arch Intern Med*. 1991;151:653–654
 189. Robert J, Fridkin SK, Blumberg HM, et al. The influence of the composition of the nursing staff on primary bloodstream infection rates in a surgical intensive care unit. *Infect Control Hosp Epidemiol*. 2000;21:12–17
 190. Vicca AF. Nursing staff workload as a determinant of methicillin-resistant *Staphylococcus aureus* spread in an adult intensive therapy unit. *J Hosp Infect*. 1999;43:109–113
 191. White MC, Ragland KE. Surveillance of intravenous catheter-related infections among home care clients. *Am J Infect Control*. 1994;22:231–235
 192. Lorenzen AN, Itkin DJ. Surveillance of infection in home care. *Am J Infect Control*. 1992;20:326–329
 193. White MC. Infections and infection risks in home care settings. *Infect Control Hosp Epidemiol*. 1992;13:535–539
 194. Raad II, Baba M, Bodey GP. Diagnosis of catheter-related infections: the role of surveillance and targeted quantitative skin cultures. *Clin Infect Dis*. 1995;20:593–597
 195. Widmer AF, Nettleman M, Flint K, Wenzel RP. The clinical impact of culturing central venous catheters: a prospective study. *Arch Intern Med*. 1992;152:1299–1302
 196. Boyce JM, Farr BM, Jarvis WR, et al. Guideline for hand hygiene in the healthcare setting. *Am J Infect Control*. 2002. In press
 197. Bischoff WE, Reynolds TM, Sessler CN, Edmond MB, Wenzel RP. Handwashing compliance by health care workers: the impact of introducing an accessible, alcohol-based hand antiseptic. *Arch Intern Med*. 2000;160:1017–1021
 198. Pittet D, Dharan S, Touveneau S, Sauvan V, Perneger TV. Bacterial contamination of the hands of hospital staff during routine patient care. *Arch Intern Med*. 1999;159:821–826
 199. Simmons B, Bryant J, Neiman K, Spencer L, Arheart K. The role of handwashing in prevention of endemic intensive care unit infections. *Infect Control Hosp Epidemiol*. 1990;11:589–594
 200. Boyce JM, Kelliher S, Vallande N. Skin irritation and dryness associated with two hand-hygiene regimens: soap-and-water hand washing versus hand antiseptics with an alcoholic hand gel. *Infect Control Hosp Epidemiol*. 2000;21:442–448
 201. Capdevila JA. Catheter-related infection: an update on diagnosis, treatment, and prevention. *Int J Infect Dis*. 1998;2:230–236
 202. Abi-Said D, Raad II, Umphrey J, Gonzalez V, Richardson D, Marts K, Hohn D. Infusion therapy team and dressing changes of central venous catheters. *Infect Control Hosp Epidemiol*. 1999;20:101–105
 203. CDC. Update: universal precautions for prevention of transmission of human immunodeficiency virus, hepatitis B virus, and other blood-borne pathogens in health-care settings. *MMWR Morb Mortal Wkly Rep*. 1988;37:377–382, 388
 204. Povoski SP. A prospective analysis of the cephalic vein cutdown approach for chronic indwelling central venous access in 100 consecutive cancer patients. *Ann Surg Oncol*. 2000;7:496–502
 205. Arrighi DA, Farnell MB, Mucha P Jr, Istrup DM, Anderson DL. Prospective, randomized trial of rapid venous access for patients in hypovolemic shock. *Ann Emerg Med*. 1989;18:927–930
 206. Ahmed Z, Mohyuddin Z. Complications associated with different insertion techniques for Hickman catheters. *Postgrad Med J*. 1998;74:104–107
 207. Little JR, Murray PR, Traynor PS, Spitznagel E. A randomized trial of povidone-iodine compared with iodine tincture for venipuncture site disinfection: effects on rates of blood culture contamination. *Am J Med*. 1999;107:119–125
 208. 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;24:1818–1823

209. Maki DG, McCormack KN. Defatting catheter insertion sites in total parenteral nutrition is of no value as an infection control measure. Controlled clinical trial. *Am J Med.* 1987;83:833–840
210. Bijma R, Girbes AR, Kleijer DJ, Zwaveling JH. Preventing central venous catheter-related infection in a surgical intensive-care unit. *Infect Control Hosp Epidemiol.* 1999;20:618–620
211. Raserio L, 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;85:275–279
212. Madeo M, Martin CR, Turner C, Kirkby V, Thompson DR. A randomized trial comparing Arglaes (a transparent dressing containing silver ions) to Tegaderm (a transparent polyurethane dressing) for dressing peripheral arterial catheters and central vascular catheters. *Intensive Crit Care Nurs.* 1998;14:187–191
213. Flowers RH, 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;261:878–883
214. Robbins J, Cromwell P, Korones DN. Swimming and central venous catheter-related infections in the child with cancer. *J Pediatr Oncol Nurs.* 1999;16:51–56
215. Howell PB, Walters PE, Donowitz GR, Farr BM. Risk factors for infection of adult patients with cancer who have tunneled central venous catheters. *Cancer.* 1995;75:1367–1375
216. Goetz AM, Miller J, Wagener MM, Muder RR. Complications related to intravenous midline catheter usage: a 2-year study. *J Intraven Nurs.* 1998;21:76–80
217. Martin C, Viviani X, Saux P, Gouin F. Upper-extremity deep vein thrombosis after central venous catheterization via the axillary vein. *Crit Care Med.* 1999;27:2626–2629
218. Robinson JF, Robinson WA, Cohn A, Garg K, Armstrong JD. Perforation of the great vessels during central venous line placement. *Arch Intern Med.* 1995;155:1225–1228
219. Lederle FA, Parenti CM, Berskow LC, Ellingson KJ. The idle intravenous catheter. *Ann Intern Med.* 1992;116:737–738
220. Parenti CM, Lederle FA, Impola CL, Peterson LR. Reduction of unnecessary intravenous catheter use: internal medicine house staff participate in a successful quality improvement project. *Arch Intern Med.* 1994;154:1829–1832
221. Thomas F, Burke JP, Parker J, et al. The risk of infection related to radial vs femoral sites for arterial catheterization. *Crit Care Med.* 1983;11:807–812
222. Nelson DB, Garland JS. The natural history of Teflon catheter-associated phlebitis in children. *Am J Dis Child.* 1987;141:1090–1092
223. Shimandle RB, Johnson D, Baker M, Stotland N, Karrison T, Arnow PM. Safety of peripheral intravenous catheters in children. *Infect Control Hosp Epidemiol.* 1999;20:736–740
224. O'Grady NP, Barie PS, Bartlett J, et al. Practice parameters for evaluating new fever in critically ill adult patients. Task Force of the American College of Critical Care Medicine of the Society of Critical Care Medicine in collaboration with the Infectious Disease Society of America. *Crit Care Med.* 1998;26:392–408
225. Mermel LA, Farr BM, Sherertz RJ, et al. Guidelines for the management of intravascular catheter-related infections. *Clin Infect Dis.* 2001;32:1249–1272
226. Mershon J, Nogami W, Williams JM, Yoder C, Eitzen HE, Lemons JA. Bacterial/fungal growth in a combined parenteral nutrition solution. *J Parenter Enteral Nutr.* 1986;10:498–502
227. Gilbert M, Gallagher SC, Eads M, Elmore MF. Microbial growth patterns in a total parenteral nutrition formulation containing lipid emulsion. *J Parenter Enteral Nutr.* 1986;10:494–497
228. Maki DG, Martin WT. Nationwide epidemic of septicemia caused by contaminated infusion products. IV. Growth of microbial pathogens in fluids for intravenous infusions. *J Infect Dis.* 1975;131:267–272
229. Didier ME, Fischer S, Maki DG. Total nutrient admixtures appear safer than lipid emulsion alone as regards microbial contamination: growth properties of microbial pathogens at room temperature. *J Parenter Enteral Nutr.* 1998;22:291–296
230. Bennett SN, McNeil MM, Bland LA, et al. Postoperative infections traced to contamination of an intravenous anesthetic, propofol. *N Engl J Med.* 1995;333:147–154
231. Roth VR, Arduino MJ, Nobiletti J, et al. Transfusion-related sepsis due to *Serratia liquefaciens* in the United States. *Transfusion.* 2000;40:931–935
232. Blajchman MA. Reducing the risk of bacterial contamination of cellular blood components. *Dev Biol Stand.* 2000;102:183–193
233. Barrett BB, Andersen JW, Anderson KC. Strategies for the avoidance of bacterial contamination of blood components. *Transfusion.* 1993;33:228–233
234. Wagner SJ, Friedman LI, Dodd RY. Transfusion-associated bacterial sepsis. *Clin Microbiol Rev.* 1994;7:290–302
235. Plott RT, Wagner RF Jr, Tyring SK. Iatrogenic contamination of multidose vials in simulated use. A reassessment of current patient injection technique. *Arch Dermatol.* 1990;126:1441–1444
236. Salzman MB, Isenberg HD, Rubin LG. Use of disinfectants to reduce microbial contamination of hubs of vascular catheters. *J Clin Microbiol.* 1993;31:475–479
237. ASHP Council on Professional Affairs. ASHP guidelines on quality assurance for pharmacy-prepared sterile products. *Am J Health Syst Pharm.* 2000;57:1150–1169
238. Herruzo-Cabrera R, Garcia-Caballero J, Vera-Cortes ML, et al. Growth of microorganisms in parenteral nutrient solutions. *Am J Hosp Pharm.* 1984;41:1178–1180
239. Green KA, Shouldachi B, Schoer K, Moro D, Blend R, McGeer A. Gadolinium-based MR contrast media: potential for growth of microbial contaminants when single vials are used for multiple patients. *AJR Am J Roentgenol.* 1995;165:669–671
240. Arrington ME, Gabbert KC, Mazgaj PW, Wolf MT. Multidose vial contamination in anesthesia. *AANA J.* 1990;58:462–466
241. Falchuk KH, Peterson L, McNeil BJ. Microparticulate-induced phlebitis: its prevention by in-line filtration. *N Engl J Med.* 1985;312:78–82
242. Cohran J, Larson E, Roach H, Blane C, Pierce P. Effect of intravascular surveillance and education program on rates of nosocomial bloodstream infections. *Heart Lung.* 1996;25:161–164
243. Netto dos Santos KR, de Souza Fonseca L, Gontijo Filho PP. Emergence of high-level mupirocin resistance in methicillin-resistant *Staphylococcus aureus* isolated from Brazilian university hospitals. *Infect Control Hosp Epidemiol.* 1996;17:813–816
244. Ryder MA. Peripheral access options. *Surg Oncol Clin North Am.* 1995;4:395–427
245. Maki DG, Goldman DA, Rhame FS. Infection control in intravenous therapy. *Ann Intern Med.* 1973;79:867–887
246. Tager IB, Ginsberg MB, Ellis SE, et al. An epidemiologic study of the risks associated with peripheral intravenous catheters. *Am J Epidemiol.* 1983;118:839–851
247. Horan TC, Emori TG. Definitions of key terms used in the NNIS System. *Am J Infect Control.* 1997;25:112–116
248. Khuri-Bulos NA, Shennak M, Agabi S, et al. Nosocomial infections in the intensive care units at a university hospital in a developing country: comparison with National Nosocomial Infections Surveillance intensive care unit rates. *Am J Infect Control.* 1999;27:547–552
249. Pittet D, Wenzel RP. Nosocomial bloodstream infections. Secular trends in rates, mortality, and contribution to total hospital deaths. *Arch Intern Med.* 1995;155:1177–1184
250. CDC. Monitoring hospital-acquired infections to promote patient safety—United States, 1990–1999. *MMWR Morb Mortal Wkly Rep.* 2000;49:149–153
251. Clark-Christoff N, Watters VA, Sparks W, Snyder P, Grant JP. Use of triple-lumen subclavian catheters for administration of total parenteral nutrition. *J Parenter Enteral Nutr.* 1992;16:403–407
252. Early TF, Gregory RT, Wheeler JR, Snyder SO Jr, Gayle RG. Increased infection rate in double-lumen versus single-lumen Hickman catheters in cancer patients. *South Med J.* 1990;83:34–36
253. Hilton E, Haslett TM, Borenstein MT, Tucci V, Isenberg HD, Singer C. Central catheter infections: single- versus triple-lumen catheters: influence of guide wires on infection rates when used for replacement of catheters. *Am J Med.* 1988;84:667–672
254. Yeung C, May J, Hughes R. Infection rate for single lumen v triple lumen subclavian catheters. *Infect Control Hosp Epidemiol.* 1988;9:154–158
255. Collin GR. Decreasing catheter colonization through the use of an antiseptic-impregnated catheter: a continuous quality improvement project. *Chest.* 1999;115:1632–1640
256. Groeger JS, Lucas AB, Thaler HT, et al. Infectious morbidity associated with long-term use of venous access devices in patients with cancer. *Ann Intern Med.* 1993;119:1168–1174
257. Pegues D, Axelrod P, McClarren C, et al. Comparison of infections in Hickman and implanted port catheters in adult solid tumor patients. *J Surg Oncol.* 1992;49:156–162
258. Moss AH, Vasilakis C, Holley JL, Foulks CJ, Pillai K, McDowell DE. Use of a silicone dual-lumen catheter with a Dacron cuff as a long-term vascular access for hemodialysis patients. *Am J Kidney Dis.* 1990;16:211–215
259. Schillinger F, Schillinger D, Montagnac R, Milcent T. Post catheteriza-

- tion vein stenosis in haemodialysis: comparative angiographic study of 50 subclavian and 50 internal jugular accesses. *Nephrol Dial Transplant*. 1991;6:722-724
260. Cimochoowski GE, Worley E, Rutherford WE, Sartain J, Blondin J, Harter H. Superiority of the internal jugular over the subclavian access for temporary dialysis. *Nephron*. 1990;54:154-161
 261. Barrett N, Spencer S, McIvor J, Brown EA. Subclavian stenosis: a major complication of subclavian dialysis catheters. *Nephrol Dial Transplant*. 1988;3:423-425
 262. Trerotola SO, Kuhn-Fulton J, Johnson MS, Shah H, Ambrosius WT, Kneebone PH. Tunneled infusion catheters: increased incidence of symptomatic venous thrombosis after subclavian versus internal jugular venous access. *Radiology*. 2000;217:89-93
 263. Macdonald S, Watt AJ, McNally D, Edwards RD, Moss JG. Comparison of technical success and outcome of tunneled catheters inserted via the jugular and subclavian approaches. *J Vasc Interv Radiol*. 2000;11:225-231
 264. Widmer AF. Management of catheter-related bacteremia and fungemia in patients on total parenteral nutrition. *Nutrition*. 1997;13(suppl):S18-S25
 265. Powell C, Kudsk KA, Kulich PA, Mandelbaum JA, Fabri PJ. Effect of frequent guidewire changes on triple-lumen catheter sepsis. *J Parenter Enteral Nutr*. 1988;12:462-464
 266. Snyderman DR, Murray SA, Kornfeld SJ, Majka JA, Ellis CA. Total parenteral nutrition-related infections: prospective epidemiologic study using semiquantitative methods. *Am J Med*. 1982;73:695-699
 267. Easom A. Prophylactic antibiotic lock therapy for hemodialysis catheters. *Nephrol Nurs J*. 2000;27:75
 268. Vercaigne LM, Sitar DS, Penner SB, Bernstein K, Wang GQ, Burczynski FJ. Antibiotic-heparin lock: in vitro antibiotic stability combined with heparin in a central venous catheter. *Pharmacotherapy*. 2000;20:394-399
 269. Donowitz LG, Marsik FJ, Hoyt JW, Wenzel RP. *Serratia marcescens* bacteremia from contaminated pressure transducers. *JAMA*. 1979;242:1749-1751
 270. Luskin RL, Weinstein RA, Nathan C, Chamberlin WH, Kabins SA. Extended use of disposable pressure transducers: a bacteriologic evaluation. *JAMA*. 1986;255:916-920
 271. Maki DG, Hassemer CA. Endemic rate of fluid contamination and related septicemia in arterial pressure monitoring. *Am J Med*. 1981;70:733-738
 272. Mermel LA, Maki DG. Epidemic bloodstream infections from hemodynamic pressure monitoring: signs of the times. *Infect Control Hosp Epidemiol*. 1989;10:47-53
 273. Tenold R, Priano L, Kim K, Rourke B, Marrone T. Infection potential of nondisposable pressure transducers prepared prior to use. *Crit Care Med*. 1987;15:582-583
 274. Leroy O, Billiau V, Beuscart C, et al. Nosocomial infections associated with long-term radial artery cannulation. *Intensive Care Med*. 1989;15:241-246
 275. Fisher MC, Long SS, Roberts EM, Dunn JM, Balsara RK. *Pseudomonas maltophilia* bacteremia in children undergoing open heart surgery. *JAMA*. 1981;246:1571-1574
 276. Stamm WE, Colella JJ, Anderson RL, Dixon RE. Indwelling arterial catheters as a source of nosocomial bacteremia: an outbreak caused by *Flavobacterium species*. *N Engl J Med*. 1975;292:1099-1102
 277. Weinstein RA, Emori TG, Anderson RL, Stamm WE. Pressure transducers as a source of bacteremia after open heart surgery: report of an outbreak and guidelines for prevention. *Chest*. 1976;69:338-344
 278. Shinozaki T, Deane RS, Mazuzan JE Jr, Hamel AJ, Hazelton D. Bacterial contamination of arterial lines: a prospective study. *JAMA*. 1983;249:223-225
 279. Solomon SL, Alexander H, Eley JW, et al. Nosocomial fungemia in neonates associated with intravascular pressure-monitoring devices. *Pediatr Infect Dis*. 1986;5:680-685
 280. Weems JJ Jr, Chamberland ME, Ward J, Willy M, Padhye AA, Solomon SL. *Candida parapsilosis* fungemia associated with parenteral nutrition and contaminated blood pressure transducers. *J Clin Microbiol*. 1987;25:1029-1032
 281. Beck-Sague CM, Jarvis WR, Brook JH, et al. Epidemic bacteremia due to *Acinetobacter baumannii* in five intensive care units. *Am J Epidemiol*. 1990;132:723-733
 282. Villarino ME, Jarvis WR, O'Hara C, Bresnahan J, Clark N. Epidemic of *Serratia marcescens* bacteremia in a cardiac intensive care unit. *J Clin Microbiol*. 1989;27:2433-2436
 283. Boo NY, Wong NC, Zulkifli SS, Lye MS. Risk factors associated with umbilical vascular catheter-associated thrombosis in newborn infants. *J Paediatr Child Health*. 1999;35:460-465
 284. Cronin WA, Germanson TP, Donowitz LG. Intravascular catheter colonization and related bloodstream infection in critically ill neonates. *Infect Control Hosp Epidemiol*. 1990;11:301-308
 285. Miller KL, Coen PE, White WJ, Hurst WJ, Achey BE, Lang CM. Effectiveness of skin absorption of tincture of I in blocking radioiodine from the human thyroid gland. *Health Phys*. 1989;56:911-914
 286. Ankola PA, Atakent YS. Effect of adding heparin in very low concentration to the infusate to prolong the patency of umbilical artery catheters. *Am J Perinatol*. 1993;10:229-232
 287. Horgan MJ, Bartoletti A, Polansky S, Peters JC, Manning TJ, Lamont BM. Effect of heparin infusates in umbilical arterial catheters on frequency of thrombotic complications. *J Pediatr*. 1987;111:774-778
 288. David RJ, Merten DF, Anderson JC, Gross S. Prevention of umbilical artery catheter clots with heparinized infusates. *Dev Pharmacol Ther*. 1981;2:117-126
 289. Fletcher MA, Brown DR, Landers S, Seguin J. Umbilical arterial catheter use: report of an audit conducted by the Study Group for Complications of Perinatal Care. *Am J Perinatol*. 1994;11:94-99
 290. Seguin J, Fletcher MA, Landers S, Brown D, Macpherson T. Umbilical venous catheterizations: audit by the Study Group for Complications of Perinatal Care. *Am J Perinatol*. 1994;11:67-70
 291. Loisel DB, Smith MM, MacDonald MG, Martin GR. Intravenous access in newborn infants: impact of extended umbilical venous catheter use on requirement for peripheral venous lines. *J Perinatol*. 1996;16:461-466
 292. Garner JS, Jarvis WR, Emori TG, Horan TC, Hughes JM. CDC definitions for nosocomial infections, 1988. *Am J Infect Control*. 1988;16:128-140
 293. Garner JS, Jarvis WR, Emori TG, Horan TC, Hughes JM. CDC definitions for nosocomial infections, 1988 [erratum]. *Am J Infect Control*. 1988;16:177

Guidelines for the Prevention of Intravascular Catheter-Related Infections
Naomi P. O'Grady, Mary Alexander, E. Patchen Dellinger, Julie L. Gerberding,
Stephen O. Heard, Dennis G. Maki, Henry Masur, Rita D. McCormick, Leonard A.
Mermel, Michele L. Pearson, Issam I. Raad, Adrienne Randolph and Robert A.
Weinstein

Pediatrics 2002;110:e51
DOI: 10.1542/peds.110.5.e51

Updated Information & Services

including high resolution figures, can be found at:
<http://pediatrics.aappublications.org/content/110/5/e51>

References

This article cites 283 articles, 27 of which you can access for free at:
<http://pediatrics.aappublications.org/content/110/5/e51#BIBL>

Subspecialty Collections

This article, along with others on similar topics, appears in the following collection(s):
Infectious Disease
http://www.aappublications.org/cgi/collection/infectious_diseases_sub

Permissions & Licensing

Information about reproducing this article in parts (figures, tables) or in its entirety can be found online at:
<http://www.aappublications.org/site/misc/Permissions.xhtml>

Reprints

Information about ordering reprints can be found online:
<http://www.aappublications.org/site/misc/reprints.xhtml>

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™



PEDIATRICS®

OFFICIAL JOURNAL OF THE AMERICAN ACADEMY OF PEDIATRICS

Guidelines for the Prevention of Intravascular Catheter-Related Infections

Naomi P. O'Grady, Mary Alexander, E. Patchen Dellinger, Julie L. Gerberding, Stephen O. Heard, Dennis G. Maki, Henry Masur, Rita D. McCormick, Leonard A. Mermel, Michele L. Pearson, Issam I. Raad, Adrienne Randolph and Robert A. Weinstein

Pediatrics 2002;110:e51

DOI: 10.1542/peds.110.5.e51

The online version of this article, along with updated information and services, is located on the World Wide Web at:

<http://pediatrics.aappublications.org/content/110/5/e51>

Pediatrics is the official journal of the American Academy of Pediatrics. A monthly publication, it has been published continuously since 1948. Pediatrics is owned, published, and trademarked by the American Academy of Pediatrics, 141 Northwest Point Boulevard, Elk Grove Village, Illinois, 60007. Copyright © 2002 by the American Academy of Pediatrics. All rights reserved. Print ISSN: 1073-0397.

American Academy of Pediatrics

DEDICATED TO THE HEALTH OF ALL CHILDREN™

