Published in final edited form as:

J Vasc Interv Radiol. 2012 August ; 23(8): 997–1007. doi:10.1016/j.jvir.2012.04.023.

Guidelines for the Prevention of Intravascular Catheter-Related Infections: Recommendations Relevant to Interventional Radiology for Venous Catheter Placement and Maintenance

Donald L. Miller, M.D.¹ and Naomi P. O'Grady, M.D.²

¹Center for Devices and Radiological Health, Food and Drug Administration, Building 66, Room 4553, 10903 New Hampshire Avenue, Silver Spring, MD 20993, 301-796-3299, donald.miller@fda.hhs.gov

²Critical Care Medicine Department, Warren G. Magnuson Clinical Center, National Institutes of Health, Bethesda MD

Keywords

Guidelines; Hemodialysis; Infection control; Vascular access; Venous access

Introduction

In the United States, 80,000 catheter-related blood stream infection (CRBSIs) occur in intensive care units each year (1), and a total of 250,000 cases of CRBSIs have been estimated to occur annually, if entire hospitals are assessed (2). In the ICU, these infections independently increase hospital costs and length of stay (3–6), but have not generally been shown to independently increase mortality.

The second edition of the Centers for Disease Control (CDC) Guidelines for the Prevention of Intravascular Catheter-Related Infections was published on August 9, 2002 in the MMWR Reports and Recommendations series (7), and replaced the original guideline, published in 1996. The goal was to provide evidence-based recommendations for preventing catheter-related infections. Selected recommendations from the 2002 guideline relevant to interventional radiology were excerpted as an SIR guideline, published in JVIR in 2003 (8, 9).

Major areas of emphasis in the 2002 CDC Guidelines included 1) educating and training healthcare 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 prevention of infection; and 5) using antiseptic/antibiotic impregnated short-term central venous catheters and chlorhexidine impregnated sponge dressings if the rate of infection is high despite adherence to other strategies (i.e. education and training, maximal sterile barrier precautions and 2% chlorhexidine for skin antisepsis).

Unfortunately, implementation of evidence-based CRBSI preventive practices in U.S. hospitals has been suboptimal (4, 10). In a national survey conducted in March 2005 of over 700 U.S. hospitals, approximately one quarter of U.S. hospitals indicated that either

maximal sterile barrier precautions during central line insertion or chlorhexidine gluconate as site disinfectant, two practices widely recommended in the 2002 guidelines, were not being used routinely (11). Approximately 15% of U.S. hospitals reported routinely changing CVCs to prevent infection despite evidence that this practice should no longer be used (4, 11).

The 2002 CDC guideline has now been revised and updated. The new document, published in 2011 (12, 13), was prepared by a working group comprising members from professional organizations representing the disciplines of critical care medicine, infectious diseases, healthcare infection control, surgery, anesthesiology, interventional radiology, pulmonary medicine, pediatric medicine, and nursing. The working group was led by the Society of Critical Care Medicine, in collaboration with the Infectious Disease Society of America, Society for Healthcare Epidemiology of America, Surgical Infection Society, American College of Chest Physicians, American Thoracic Society, American Society of Critical Care Anesthesiologists, Association for Professionals in Infection Control and Epidemiology, Infusion Nurses Society, Oncology Nursing Society, American Society for Parenteral and Enteral Nutrition, the Society of Interventional Radiology, American Academy of Pediatrics, Pediatric Infectious Diseases Society, and the Healthcare Infection Control Practices Advisory Committee of the CDC.

The 83-page electronic version of the 2011 CDC guideline is available online without charge (<http://www.cdc.gov/hicpac/pdf/guidelines/bsi-guidelines-2011.pdf>). Major areas of emphasis in the 2011 guideline include 1) educating and training healthcare personnel who insert and maintain catheters; 2) using maximal sterile barrier precautions during central venous catheter insertion; 3) using a > 0.5% chlorhexidine skin preparation with alcohol for 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 and chlorhexidine impregnated sponge dressings if the rate of infection is not decreasing despite adherence to other strategies (i.e., education and training, maximal sterile barrier precautions, and >0.5% chlorhexidine preparations with alcohol for skin antisepsis).

The CDC guideline is lengthy and includes recommendations regarding peripheral venous catheters, hand hygiene, umbilical catheters, peripheral arterial catheters and replacement of administration sets and needleless intravascular catheter systems. These topics are not reviewed here. Portions of the new guideline are of particular interest to interventional radiologists, particularly those dealing with central venous catheters (CVCs), peripherally inserted central catheters (PICCs) and hemodialysis catheters. This revised SIR guideline contains selected recommendations from the 2011 CDC guideline, presented verbatim, along with selected supporting data, background information, and references.

Definitions

Catheter-related bloodstream infection (CRBSI): a clinical definition, used when diagnosing and treating patients, which requires specific laboratory testing to identify more thoroughly the catheter as the source of the bloodstream infection. It is often problematic to precisely establish if a bloodstream infection is a CRBSI due to the clinical needs of the patient (the catheter is not always removed), limited availability of microbiologic methods (many laboratories do not use quantitative blood cultures or differential time to positivity), and procedural compliance by direct care personnel (labeling must be accurate).

Central line-associated bloodstream infection (CLABSI): term used by CDC's National Healthcare Safety Network. A CLABSI is a primary bloodstream infection in a patient who had a central line within the 48-hour period before the development of the bloodstream infection, and is not related to an infection at another site. However, since some bloodstream

infections are secondary to other sources (other than the central line) that may not be easily recognized (e.g., pancreatitis, mucositis), the CLABSI surveillance definition may overestimate the true incidence of CRBSI.

Microbiology

The most commonly reported causative pathogens remain coagulase-negative staphylococci, *Staphylococcus aureus*, enterococci, and *Candida* species (14). Gram-negative bacilli accounted for 19% and 21% of CLABSIs reported to CDC (15) and the Surveillance and Control of Pathogens of Epidemiological Importance (SCOPE) database, respectively (14).

For all common pathogens causing CLABSIs, antimicrobial resistance is a problem, particularly in ICUs. Although methicillin-resistant *Staphylococcus aureus* (MRSA) now account for more than 50% of all *Staphylococcus aureus* isolates obtained in ICUs, the incidence of MRSA CLABSIs has decreased in recent years, perhaps as a result of prevention efforts (16). For gram-negative rods, antimicrobial resistance to third generation cephalosporins among *Klebsiella pneumoniae* and *E. coli* has increased significantly as has imipenem and ceftazidime resistance among *Pseudomonas aeruginosa* (15). *Candida* species are increasingly noted to be fluconazole resistant.

Pathogenesis

There are four recognized routes for contamination of catheters: 1) migration of skin organisms at the insertion site into the cutaneous catheter tract and along the surface of the catheter with colonization of the catheter tip (the most common route of infection for short-term catheters) (17–19); 2) direct contamination of the catheter or catheter hub by contact with hands or contaminated fluids or devices (20, 21); 3) hematogenous seeding from another focus of infection (less common) (22); and 4) infusate contamination (rare) (23).

Important pathogenic determinants of CRBSI are 1) characteristics of the device material; 2) host factors, protein adhesions, such as fibrin and fibronectin, that form a sheath around the catheter (24); and 3) the intrinsic virulence factors of the infecting organism, including the extracellular polymeric substance (EPS) produced by the adherent organisms (25).

Due to fibrin sheath formation, silastic catheters are associated with higher risk of catheter infections than polyurethane catheters (24). On the other hand, biofilm formation by *C. albicans* occurs more readily on silicone elastomer catheter surfaces than on polyurethane catheters (26). Modification of the biomaterial surface properties has been shown to influence the ability of *C. albicans* to form biofilm (27). Some catheter materials have surface irregularities that enhance the microbial adherence of certain species (e.g., *S. epidermidis* and *C. albicans*) (26, 27). Catheters made of these materials are particularly vulnerable to microbial colonization and subsequent infection. Additionally, certain catheter materials are more thrombogenic than others, a characteristic that might also predispose to catheter colonization and infection (28, 29). This association has led to emphasis on preventing catheter-related thrombus as an additional mechanism for reducing CRBSI (30, 31).

Host factors are also important in the pathogenesis of CRBSI, as they affect the adherence properties of a given microorganism. For example, *S. aureus* can adhere to host proteins (e.g., fibrinogen, fibronectin) commonly present on catheters by expressing clumping factors that bind to the protein adhesins (24, 29, 32, 33). Microbial adherence is also enhanced through the production, by microbial organisms such as coagulase negative staphylococci (34, 35), *S. aureus* (36), *Pseudomonas aeruginosa* (37), and *Candida* species (38), of an EPS that consists mostly of an exopolysaccharide that forms a microbial biofilm layer (25, 39).

This biofilm matrix is enriched by divalent metallic cations, such as calcium, magnesium and iron, enabling microbial organisms to embed themselves (40–42). These biofilms potentiate the pathogenicity of various microbes by allowing them to withstand host defense mechanisms (e.g., acting as a barrier to engulfment and killing by polymorphonuclear leukocytes) or by making them less susceptible to antimicrobial agents (e.g., forming a matrix that binds antimicrobials before their contact with the organism cell wall or providing for a population of metabolically quiescent, antimicrobial tolerant "persister" cells) (35, 43, 44). In the presence of dextrose-containing fluids, some *Candida* species produce slime similar to that of their bacterial counterparts, potentially explaining the increased proportion of BSIs caused by fungal pathogens among patients receiving parenteral nutrition fluids (45).

Classification of Recommendations

The 2011 CDC guideline contains a Summary of Recommendations with 99 specific recommendations. Each is categorized as 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; or an accepted practice (e.g., aseptic technique) supported by limited evidence), 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), or Unresolved issue (represents an unresolved issue for which evidence is insufficient or no consensus regarding efficacy exists). The recommendations most relevant to the practice of interventional radiology are given below, with supporting information and references (the organization and numbering used here are different from those used in the CDC guideline).

General recommendations

1. Periodically assess knowledge of and adherence to guidelines for all personnel involved in the insertion and maintenance of intravascular catheters (46–54). Category IA
2. Designate only trained personnel who demonstrate competence for the insertion and maintenance of peripheral and central intravascular catheters (53–61). Category IA
3. Do not administer systemic antimicrobial prophylaxis routinely before insertion or during use of an intravascular catheter to prevent catheter colonization or CRBSI (62). Category IB
4. Do not routinely use anticoagulant therapy to reduce the risk of catheter-related infection in general patient populations (63). Category II

Catheter and site selection

1. Use a midline catheter or peripherally inserted central catheter (PICC), instead of a short peripheral catheter, when the duration of IV therapy will likely exceed six days. Category II
2. Use a fistula or graft in patients with chronic renal failure instead of a CVC for permanent access for dialysis (64). Category 1A
3. Use a CVC with the minimum number of ports or lumens essential for the management of the patient (65–68). Category IB

4. No recommendation can be made regarding the use of a designated lumen for parenteral nutrition. Unresolved issue
5. Promptly remove any intravascular catheter that is no longer essential (69–72). Category IA
6. Weigh the risks and benefits of placing a central venous device at a recommended site to reduce infectious complications against the risk for mechanical complications (e.g., pneumothorax, subclavian artery puncture, subclavian vein laceration, subclavian vein stenosis, hemothorax, thrombosis, air embolism, and catheter misplacement) (17, 73–88). Category IA
7. Avoid using the femoral vein for central venous access in adult patients (73, 85, 86, 89). Category 1A
8. Use a subclavian site, rather than a jugular or a femoral site, in adult patients to minimize infection risk for nontunneled CVC placement (85–87). Category IB
9. No recommendation can be made for a preferred site of insertion to minimize infection risk for a tunneled CVC. Unresolved issue
10. Avoid the subclavian site in hemodialysis patients and patients with advanced kidney disease, to avoid subclavian vein stenosis (88, 90–93). Category IA

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 in part on the density of local skin flora.

The density of skin flora at the catheter insertion site is a major risk factor for CRBSI. No single trial has satisfactorily compared infection rates for catheters placed in jugular, subclavian, and femoral veins. In retrospective observational studies, catheters inserted into an internal jugular vein have usually been associated with higher risk for colonization and/or CRBSI than those inserted into a subclavian (17, 73–82). Similar findings were noted in neonates in a single retrospective study (94).

Femoral catheters have been demonstrated to have high colonization rates compared with subclavian and internal jugular sites when used in adults and, in some studies, higher rates of CLABSIs (75, 80–82, 85, 86, 95). Femoral catheters are also associated with a higher risk for deep venous thrombosis than are internal jugular or subclavian catheters (83–85, 88, 96). One study found that the risk of infection associated with catheters placed in the femoral vein is accentuated in obese patients (73). In contrast to adults, 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 non-femoral catheters (97–100). Thus, in adult patients, a subclavian site is preferred for infection control purposes, although other factors (e.g., the potential for mechanical complications, risk for subclavian vein stenosis, and operator skill) should be considered when deciding where to place the catheter.

Catheters should be inserted at as great a distance as possible from open wounds. In one study, catheters inserted close to open burn wounds (i.e., when the wound overlapped the 25 cm² area surrounding the catheter insertion site) were 1.79 times more likely to be colonized and 5.12 times more likely to be associated with bacteremia than catheters inserted farther from the wounds (101).

Antimicrobial/antiseptic impregnated catheters and cuffs

1. Use a chlorhexidine/silver sulfadiazine or minocycline/rifampin -impregnated CVC in patients whose catheter is expected to remain in place > 5 days if, after

successful implementation of a comprehensive strategy to reduce rates of CLABSI, the CLABSI rate is not decreasing. The comprehensive strategy should include at least the following three components: educating persons who insert and maintain catheters, use of maximal sterile barrier precautions, and a > 0.5% chlorhexidine preparation with alcohol for skin antisepsis during CVC insertion (102–108).

Category IA

Certain catheters that are coated or impregnated with antimicrobial or antiseptic agents can decrease the risk for CRBSI and could potentially decrease hospital costs associated with treating CRBSIs, despite the higher prices of antimicrobial or antiseptic impregnated catheters (108).

Nearly all of the studies involving antimicrobial/antiseptic-impregnated catheters have been conducted using triple-lumen, uncuffed catheters in adult patients whose catheters remained in place <30 days. These catheters have been approved by FDA for use in patients weighing >3 kg. Two non-randomized studies in pediatric ICU patients suggest that these catheters might reduce the risk of catheter-associated infection (107, 109). No antiseptic or antimicrobial impregnated catheters currently are available for use in infants weighing <3kg.

Two meta-analyses of catheters coated with chlorhexidine/silver sulfadiazine on the external luminal surface only (first-generation catheters) demonstrated that these catheters reduced the risk for CRBSI compared with standard non-coated catheters (1, 110). The duration of catheter placement in one study ranged from 5.1 to 11.2 days (111). A second-generation catheter is now available with chlorhexidine coating the internal surface, extending into the extension set and hubs, while the external luminal surface is coated with chlorhexidine and silver sulfadiazine. The external surface has three times the amount of chlorhexidine and extended release of the surface bound antiseptics compared to the first generation catheters. All three prospective, randomized studies of second-generation catheters demonstrated a significant reduction in catheter colonization, but they were underpowered to show a difference in CRBSI (103–105). Prolonged anti-infective activity provides improved efficacy in preventing infections (112). Although rare, anaphylaxis with the use of these chlorhexidine/silver sulfadiazine catheters has been observed (113–117).

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 (102). The beneficial effect began after day 6 of catheterization. Silicone minocycline/rifampin impregnated CVCs with an average dwell time of over 60 days have been shown to be effective in reducing CRBSI (106). No minocycline/rifampin-resistant organisms were reported in these studies. Two trials demonstrated that use of these catheters significantly reduced CRBSI compared with uncoated catheters (106, 108). No comparative studies have been published using the second-generation chlorhexidine/silver sulfadiazine catheter. Several prospective clinical studies have shown that the risk for development of resistance is low (118, 119). No resistance to minocycline or rifampin related to the use of the catheter has been documented in the clinical setting.

A combination platinum/silver impregnated catheter (i.e, a silver iontophoretic catheter) is available for use in the United States. Several prospective, randomized studies have been published comparing these catheters to uncoated catheters (120–123). One study showed a reduction in the incidence of catheter colonization and CRBSI (122), but the other studies found no difference in catheter colonization or CRBSI between the impregnated catheter and a non-impregnated catheter (74, 120, 121).

Barrier precautions

1. Use maximal sterile barrier precautions, including the use of a cap, mask, sterile gown, sterile gloves, and a sterile full body drape, for the insertion of CVCs, PICCs, or guidewire exchange (53, 124–126). Category IB
2. Use new sterile gloves before handling the new catheter when guidewire exchanges are performed. Category II
3. Wear either clean or sterile gloves when changing the dressing on intravascular catheters. Category IC
4. When adherence to aseptic technique cannot be ensured (i.e catheters inserted during a medical emergency), replace the catheter as soon as possible, i.e, within 48 hours (17, 28, 126–128). Category IB

Maximum sterile barrier (MSB) precautions are defined as wearing a sterile gown, sterile gloves, and cap and using a sterile full body drape during CVC placement. Maximal sterile barrier precautions during insertion of CVC were compared with sterile gloves and a small drape in a randomized controlled trial (124). The MSB group had fewer episodes of both catheter colonization (RR = .32, 95% CI, 0.10–0.96, $P = .04$) and CR-BSI (RR = .16, 95% CI, 0.02–1.30, $P = .06$). In addition, in the group where MSB precautions were used, infections occurred much later and contained gram negative, rather than gram positive, organisms. A study of pulmonary artery catheters also secondarily demonstrated that use of MSB precautions lowered risk of infection (17). Another study evaluated an educational program directed at improving infection control practices, especially MSB precautions (53). In this study, MSB precautions use increased and CRBSI decreased. A small trial demonstrated a reduced risk of skin colonization at the insertion site when MSB precautions were used [OR 3.40, 95%CI 1.32 to 3.67] (125).

Skin preparation

1. Prepare clean skin with a > 0.5% chlorhexidine preparation with alcohol before central venous catheter and peripheral arterial catheter insertion and during dressing changes. If there is a contraindication to chlorhexidine, tincture of iodine, an iodophor, or 70% alcohol can be used as alternatives (129, 130). Category IA
2. No comparison has been made between using chlorhexidine preparations with alcohol and povidone-iodine in alcohol to prepare clean skin. Unresolved issue.
3. Antiseptics should be allowed to dry according to the manufacturer's recommendation prior to placing the catheter (129, 130). Category IB

Two well-designed studies evaluating the chlorhexidine-containing cutaneous antiseptic regimen in comparison with either povidone iodine or alcohol for the care of an intravascular catheter insertion site have shown lower rates of catheter colonization or CRBSI associated with the chlorhexidine preparation (129, 130). (A comparison of chlorhexidine gluconate alcohol to povidone iodine alcohol has not been done.) When 0.5% tincture of chlorhexidine was compared with 10% povidone iodine, no differences were seen in central venous catheter (CVC) colonization or in CRBSI (131). In a three-armed study (2% aqueous chlorhexidine gluconate vs. 10% povidone-iodine vs. 70% alcohol), 2% aqueous chlorhexidine gluconate tended to decrease CRBSI compared with 10% povidone iodine or 70% alcohol (129). A meta-analysis of 4,143 catheters suggested that chlorhexidine preparation reduced the risk of catheter related infection by 49% (95% CI .28 to .88) relative to povidone iodine (132). An economic decision analysis based on available evidence suggested that the use of chlorhexidine, rather than povidone iodine, for CVC care would result in a 1.6% decrease in the incidence of CRBSI, a 0.23% decrease in the

incidence of death, and a savings of \$113 per catheter used (133). While chlorhexidine has become a standard antiseptic for skin preparation for the insertion of both central and peripheral venous catheters, 5% povidone iodine solution in 70% ethanol was associated with a substantial reduction of CVC-related colonization and infection compared with 10% aqueous povidone iodine (134).

Dressings

1. Use either sterile gauze or a sterile, transparent, semipermeable dressing to cover the catheter site (135–138). Category IA
 2. If the patient is diaphoretic or if the site is bleeding or oozing, use a gauze dressing until this is resolved (135–138). Category II
 3. Do not use topical antibiotic ointment or creams on insertion sites, except for dialysis catheters, because of their potential to promote fungal infections and antimicrobial resistance (139, 140). Category IB
 4. Do not submerge the catheter or catheter site in water. Showering should be permitted if precautions can be taken to reduce the likelihood of introducing organisms into the catheter (e.g., if the catheter and connecting device are protected with an impermeable cover during the shower) (141–143). Category IB
 5. Replace dressings used on short-term CVC sites every 2 days for gauze dressings. Category II
 6. Replace dressings used on short-term CVC sites at least every 7 days for transparent dressings, except in those pediatric patients in whom the risk for dislodging the catheter may outweigh the benefit of changing the dressing (138, 144). Category IB
 7. Replace transparent dressings used on tunneled or implanted CVC sites no more often than once per week (unless the dressing is soiled or loose), until the insertion site has healed. Category II
 8. 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
12. Use a chlorhexidine-impregnated sponge dressing for temporary short-term catheters in patients older than 2 months of age if the CLABSI rate is not decreasing despite adherence to basic prevention measures, including education and training, appropriate use of chlorhexidine for skin antisepsis, and MSB (REFS). Category IB
13. No recommendation is made for other types of chlorhexidine dressings. Unresolved issue

A meta-analysis has assessed studies that compared the risk for CRBSIs using transparent dressings versus using gauze dressings (145). 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, a gauze dressing is preferred. Another systematic review of randomized controlled trials comparing gauze and tape to transparent dressings found no significant differences between dressing types in CRBSIs, catheter tip colonization, or skin colonization (146).

Chlorhexidine impregnated dressings have been used to reduce the risk of CRBSI. In the largest multicenter randomized controlled trial published to date comparing chlorhexidine impregnated sponge dressings vs standard dressings in ICU patients, rates of CRBSIs were

reduced even when background rates of infection were low. In this study, 1636 patients (3778 catheters, 28 931 catheter-days) were evaluated. The chlorhexidine-impregnated sponge dressings decreased the rates of CRBSIs (10/1953 [0.5%], 0.6 per 1000 catheter-days vs 19/1825 [1.1%], 1.4 per 1000 catheter-days; hazard ratio [HR], 0.39 [95% confidence interval {CI}, 0.17–0.93]; $P = .03$) and CRBSIs (6/1953 catheters, 0.40 per 1000 catheter-days vs 17/1825 catheters, 1.3 per 1000 catheter-days; HR, 0.24 [95% CI, 0.09–0.65]) [148]. A randomized controlled study of polyurethane or a chlorhexidine impregnated sponge dressing in 140 children showed no statistical difference in BSIs; however, the chlorhexidine group had lower rates of CVC colonization [153]. In 601 cancer patients receiving chemotherapy, the incidence of CRBSI was reduced in patients receiving the chlorhexidine impregnated sponge dressing compared to standard dressings ($p = 0.016$, relative risk 0.54; confidence interval 0.31–0.94) [159]. A meta-analysis that included eight randomized controlled trials demonstrated that chlorhexidine impregnated sponge dressings are associated with a reduction of vascular and epidural catheter exit site colonization but no significant reduction in CRBSI (2.2% versus 3.8%, OR 0.58, 95% CI: 0.29–1.14, $P = 0.11$) [152].

Although data regarding the use of a chlorhexidine impregnated sponge dressing in children are limited, one randomized, controlled study involving 705 neonates reported a substantial decrease in colonized catheters in infants in the chlorhexidine impregnated sponge dressing 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. Chlorhexidine impregnated sponge dressings were associated with localized contact dermatitis in infants of very low birth weight. In 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 [151].

Catheter securement

1. Use a sutureless securement device to reduce the risk of infection for intravascular catheters (147). Category II

Catheter stabilization is recognized as an intervention to decrease the risk of phlebitis, catheter migration and dislodgement, and may be advantageous in preventing CRBSIs. Pathogenesis of CRBSI occurs via migration of skin flora through the percutaneous entry site. Sutureless securement devices avoid disruption around the catheter entry site and may decrease the degree of bacterial colonization. (147). Using a sutureless securement device also mitigates the risk of sharps injury to the healthcare provider from inadvertent needlestick injury.

Dialysis catheter management

1. Use povidone iodine antiseptic ointment or bacitracin/gramicidin/polymyxin B 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 the manufacturer's recommendation (64, 148–152). Category IB
2. Use prophylactic antimicrobial lock solution in patients with long term catheters who have a history of multiple CRBSI despite optimal maximal adherence to aseptic technique (153–169). Category II

A variety of topical antibiotic or antiseptic ointments have been utilized in attempts to lower the antimicrobial burden at the catheter insertion site and thus prevent infection. More recent studies have examined this approach in high-risk patients, particularly those undergoing hemodialysis (149–152). Three randomized, controlled trials have evaluated the use of 10% povidone iodine (150–152). A significant decrease in colonization, exit-site infection, or bloodstream infection was observed. The beneficial effect was most prominent in subjects with nasal colonization by *Staphylococcus aureus* (150–152).

In the only study demonstrating a significant effect on mortality, the application of bacitracin/gramicidin/polymyxin B ointment at the catheter insertion site was compared with placebo in 169 hemodialysis patients (170). There is evidence from this study that bacitracin/gramicidin/polymyxin B ointment can improve outcome, but no similar data exist for use in other patient populations (170). Gramicidin-containing ointment is not currently available in the United States.

At least 10 studies regarding catheter flush or lock solutions have been performed in hemodialysis patients (160–169). Three meta-analyses have all demonstrated that catheter lock solutions reduce risk of CRBSI in hemodialysis patients (171–173). In the largest of these studies, 291 subjects were enrolled in a prospective randomized comparison of 30% trisodium citrate versus heparin (164). The rate of CRBSI was significantly lower in the group whose catheters were locked with trisodium citrate (4.1 BSI/1,000 CVC days vs. 1.1 BSI/1,000 CVC days, $P < .001$), and no significant difference in thrombosis or occlusion of the catheter was noted. However, if infused rapidly, concentrated citrate can result in serious hypocalcaemia, cardiac dysrhythmia, and death. The second largest study in hemodialysis subjects examined the effect of a catheter lock solution containing cefazolin, gentamicin, and heparin compared with control patients receiving only heparin (166). In 120 subjects, the rate of CRBSI was significantly lower in those receiving the antibiotic lock solution (0.44 BSI/1,000 CVC days vs. 3.12 BSI/1,000 CVC days, $P = .03$) (166). Other trials in hemodialysis patients have studied minocycline, gentamicin, EDTA, heparin, taurolidine, vancomycin, and cefotaxime.

Replacement of midline catheters

1. Replace midline catheters only when there is a specific indication. Category II

Midline catheters are associated with lower rates of phlebitis than short peripheral catheters and with lower rates of infection than CVCs (174–176). In one prospective study of 140 midline catheters, their use was associated with a BSI rate of 0.8 per 1,000 catheter days (176). 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 could 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.

Replacement of CVCs

1. Do not routinely replace CVCs, PICCs, hemodialysis catheters, or pulmonary artery catheters to prevent catheter-related infections. Category IB
2. 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. Category II

3. Do not use guidewire exchanges routinely for non-tunneled catheters to prevent infection. Category IB
4. Do not use guidewire exchanges to replace a non-tunneled catheter suspected of infection. Category IB
5. Use a guidewire exchange to replace a malfunctioning non-tunneled catheter if no evidence of infection is present. Category IB
6. Use new sterile gloves before handling the new catheter when guidewire exchanges are performed. Category II

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 (177, 178). One of these studies involved 112 surgical ICU patients who required CVCs, pulmonary artery catheters, or peripheral arterial catheters (177), whereas the other study involved only subclavian hemodialysis catheters (178). 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 exchange 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 demonstrate any reduction of CRBSI rates through routine replacement of CVCs by guidewire exchange compared with catheter replacement on an as needed basis (179). Thus, routine replacement of CVCs is not necessary for catheters that are functioning and have no evidence of causing local or systemic complications.

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 (17, 180). However, in selected patients with tunneled hemodialysis catheters and bacteremia, catheter exchange over a guidewire, in combination with antibiotic therapy, is an alternative as a salvage strategy in patients with limited venous access (181–185).

The use of catheters for hemodialysis is the most common factor contributing to bacteremia in dialysis patients (186, 187). The relative risk for bacteremia in patients with dialysis catheters is seven times the risk for patients with arteriovenous (AV) fistulas (188). AV fistulas and grafts are preferred over hemodialysis catheters in patients with chronic renal failure, due to their lower associated risk of infection. If temporary access is needed for dialysis, a tunneled cuffed catheter is preferable to a non-cuffed catheter, even in the ICU setting, if the catheter is expected to stay in place for > 3 weeks (64).

Summary

The 2011 *Guidelines for the Prevention of Intravascular Catheter-Related Infections* contain comprehensive, current recommendations for the selection, placement, maintenance and replacement of catheters used for venous access. This material is directly relevant to the day-to-day practice of interventional radiology. Highlights of the *Guidelines* are presented here. The *Guidelines* contain additional recommendations related to pediatric use, arterial lines and other topics, and extensive background information and references. Review of the entire document is suggested for all physicians who perform venous access procedures.

References

1. Mermel LA. Prevention of intravascular catheter-related infections. *Ann Intern Med.* 2000; 132:391–402. [PubMed: 10691590]
2. Maki DG, Kluger DM, Crnich CJ. The risk of bloodstream infection in adults with different intravascular devices: a systematic review of 200 published prospective studies. *Mayo Clinic proceedings Mayo Clinic.* 2006; 81(9):1159–1171. [PubMed: 16970212]
3. 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. [PubMed: 11177147]
4. Warren DK, Quadir WW, Hollenbeak CS, Elward AM, Cox MJ, Fraser VJ. Attributable cost of catheter-associated bloodstream infections among intensive care patients in a nonteaching hospital. *Crit Care Med.* 2006; 34(8):2084–2089. [PubMed: 16763511]
5. Blot SI, Depuydt P, Annemans L, et al. Clinical and economic outcomes in critically ill patients with nosocomial catheter-related bloodstream infections. *Clin Infect Dis.* 2005; 41(11):1591–1598. [PubMed: 16267731]
6. Renaud B, Brun-Buisson C. Outcomes of primary and catheter-related bacteremia A cohort and case-control study in critically ill patients. *Am J Respir Crit Care Med.* 2001; 163(7):1584–1590. [PubMed: 11401878]
7. Centers for Disease Control. Guidelines for the prevention of intravascular catheter-related infections. *Mortality and Morbidity Weekly Reports.* 2002; 51(No. RR 10):1–36.
8. Miller DL, O'Grady NP. Guidelines for the prevention of intravascular catheter-related infections: recommendations relevant to interventional radiology. *J Vasc Interv Radiol.* 2003; 14(2 Pt 1):133–136. [PubMed: 12582182]
9. Miller DL, O'Grady NP. Guidelines for the prevention of intravascular catheter-related infections: recommendations relevant to interventional radiology. *J Vasc Interv Radiol.* 2003; 14(9 Pt 2):S355–S368. [PubMed: 14514845]
10. Safdar N, Maki DG. Lost in translation. *Infect Control Hosp Epidemiol.* 2006; 27(1):3–7. [PubMed: 16418979]
11. Krein SL, Hofer TP, Kowalski CP, et al. Use of central venous catheter-related bloodstream infection prevention practices by US hospitals. *Mayo Clin Proc.* 2007; 82(6):672–678. [PubMed: 17550746]
12. O'Grady NP, Alexander M, Burns LA, et al. Guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis.* 2011; 52(9):e162–e193. [PubMed: 21460264]
13. O'Grady NP, Alexander M, Burns LA, et al. Summary of recommendations: guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis.* 2011; 52(9):1087–1099. [PubMed: 21467014]
14. Wisplinghoff H, Bischoff T, Tallent SM, Seifert H, Wenzel RP, Edmond MB. Nosocomial bloodstream infections in US hospitals: analysis of 24,179 cases from a prospective nationwide surveillance study. *Clin Infect Dis.* 2004; 39(3):309–317. [PubMed: 15306996]
15. Gaynes R, Edwards JR. Overview of nosocomial infections caused by gram-negative bacilli. *Clin Infect Dis.* 2005; 41(6):848–854. [PubMed: 16107985]
16. Burton DC, Edwards JR, Horan TC, Jernigan JA, Fridkin SK. Methicillin-resistant *Staphylococcus aureus* central line-associated bloodstream infections in US intensive care units, 1997–2007. *Jama.* 2009; 301(7):727–736. [PubMed: 19224749]
17. 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; 91:197S–205S. [PubMed: 1928165]
18. Safdar N, Maki DG. The pathogenesis of catheter-related bloodstream infection with noncuffed short-term central venous catheters. *Intensive Care Med.* 2004; 30(1):62–67. [PubMed: 14647886]
19. Maki DG, Weise CE, Sarafin HW. A semiquantitative culture method for identifying intravenous-catheter-related infection. *New England Journal of Medicine.* 1977; 296:1305–1309. [PubMed: 323710]

20. Raad I, Costerton W, Sabharwal U, Sacilowski M, Anaissie E, Bodey GP. Ultrastructural analysis of indwelling vascular catheters: a quantitative relationship between luminal colonization and duration of placement. *Journal of Infectious Disease*. 1993; 168:400–447.
21. Dobbins BM, Kite P, Kindon A, McMahon MJ, Wilcox MH. DNA fingerprinting analysis of coagulase negative staphylococci implicated in catheter related bloodstream infections. *J Clin Pathol*. 2002; 55(11):824–828. [PubMed: 12401819]
22. Anaissie E, Samonis G, Kontoyiannis D, et al. Role of catheter colonization and infrequent hematogenous seeding in catheter-related infections. *Eur J Clin Microbiol Infect Dis*. 1995; 14(2): 134–137. [PubMed: 7758480]
23. Raad I, 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(3):136–139. [PubMed: 11310690]
24. Mehall JR, Saltzman DA, Jackson RJ, Smith SD. Fibrin sheath enhances central venous catheter infection. *Crit Care Med*. 2002; 30(4):908–912. [PubMed: 11940768]
25. Donlan RM, Costerton JW. Biofilms: survival mechanisms of clinically relevant microorganisms. *Clin Microbiol Rev*. 2002; 15(2):167–193. [PubMed: 11932229]
26. Hawser SP, Douglas LJ. Biofilm formation by *Candida* species on the surface of catheter materials in vitro. *Infect Immun*. 1994; 62(3):915–921. [PubMed: 8112864]
27. Stillman RM, Soliman F, Garcia L, Sawyer PN. Etiology of catheter-associated sepsis Correlation with thrombogenicity. *Arch Surg*. 1977; 112(12):1497–1499. [PubMed: 931638]
28. 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(13):1014–1016. [PubMed: 8139059]
29. 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(1):279–288. [PubMed: 1987042]
30. Shanks RM, Sargent JL, Martinez RM, Graber ML, O'Toole GA. Catheter lock solutions influence staphylococcal biofilm formation on abiotic surfaces. *Nephrol Dial Transplant*. 2006; 21(8):2247–2255. [PubMed: 16627606]
31. Chatzinikolaou I, Zipf TF, Hanna H, et al. Minocycline-ethylenediaminetetraacetate lock solution for the prevention of implantable port infections in children with cancer. *Clin Infect Dis*. 2003; 36(1):116–119. [PubMed: 12491212]
32. McDevitt D, Francois P, Vaudaux P, Foster TJ. Identification of the ligand-binding domain of the surface-located fibrinogen receptor (clumping factor) of *Staphylococcus aureus*. *Mol Microbiol*. 1995; 16(5):895–907. [PubMed: 7476187]
33. Ni Eidhin D, Perkins S, Francois P, Vaudaux P, Hook M, Foster TJ. Clumping factor B (ClfB), a new surface-located fibrinogen-binding adhesin of *Staphylococcus aureus*. *Mol Microbiol*. 1998; 30(2):245–257. [PubMed: 9791170]
34. Mack D, Davies AP, Harris LG, Rohde H, Horstkotte MA, Knobloch JK. Microbial interactions in *Staphylococcus epidermidis* biofilms. *Anal Bioanal Chem*. 2007; 387(2):399–408. [PubMed: 16955256]
35. von Eiff C, Peters G, Heilmann C. Pathogenesis of infections due to coagulase-negative staphylococci. *Lancet Infect Dis*. 2002; 2(11):677–685. [PubMed: 12409048]
36. Zhu Y, Weiss EC, Otto M, Fey PD, Smeltzer MS, Somerville GA. *Staphylococcus aureus* biofilm metabolism and the influence of arginine on polysaccharide intercellular adhesin synthesis, biofilm formation, and pathogenesis. *Infect Immun*. 2007; 75(9):4219–4226. [PubMed: 17576756]
37. Murga R, Miller JM, Donlan RM. Biofilm formation by gram-negative bacteria on central venous catheter connectors: effect of conditioning films in a laboratory model. *J Clin Microbiol*. 2001; 39(6):2294–2297. [PubMed: 11376074]
38. Douglas LJ. *Candida* biofilms and their role in infection. *Trends Microbiol*. 2003; 11(1):30–36. [PubMed: 12526852]
39. Donlan RM. Biofilms: microbial life on surfaces. *Emerg Infect Dis*. 2002; 8(9):881–890. [PubMed: 12194761]

40. Dunne WM Jr, Burd EM. The effects of magnesium, calcium, EDTA, and pH on the in vitro adhesion of *Staphylococcus epidermidis* to plastic. *Microbiol Immunol*. 1992; 36(10):1019–1027. [PubMed: 1479958]
41. Ozerdem Akpolat N, Elçi S, Atmaca S, Akbayin H, Gül K. The effects of magnesium, calcium and EDTA on slime production by *Staphylococcus epidermidis* strains. *Folia Microbiol (Praha)*. 2003; 48(5):649–653. [PubMed: 14976723]
42. Banin E, Brady KM, Greenberg EP. Chelator-induced dispersal and killing of *Pseudomonas aeruginosa* cells in a biofilm. *Appl Environ Microbiol*. 2006; 72(3):2064–2069. [PubMed: 16517655]
43. Donlan RM. Role of biofilms in antimicrobial resistance. *Asaio J*. 2000; 46(6):S47–S52. [PubMed: 11110294]
44. Farber BF, Kaplan MH, Clogston AG. *Staphylococcus epidermidis* extracted slime inhibits the antimicrobial action of glycopeptide antibiotics. *J Infect Dis*. 1990; 161(1):37–40. [PubMed: 2295856]
45. 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(2):452–456. [PubMed: 8150956]
46. Yoo S, Ha M, Choi D, Pai H. Effectiveness of surveillance of central catheter-related bloodstream infection in an ICU in Korea. *Infect Control Hosp Epidemiol*. 2001; 22(7):433–436. [PubMed: 11583212]
47. Warren DK, Zack JE, Cox MJ, Cohen MM, Fraser VJ. An educational intervention to prevent catheter-associated bloodstream infections in a nonteaching, community medical center. *Crit Care Med*. 2003; 31(7):1959–1963. [PubMed: 12847389]
48. Warren DK, Zack JE, Mayfield JL, et al. The effect of an education program on the incidence of central venous catheter-associated bloodstream infection in a medical ICU. *Chest*. 2004; 126(5):1612–1618. [PubMed: 15539735]
49. Warren DK, Cosgrove SE, Diekema DJ, et al. A multicenter intervention to prevent catheter-associated bloodstream infections. *Infect Control Hosp Epidemiol*. 2006; 27(7):662–669. [PubMed: 16807839]
50. Higuera F, Rosenthal VD, Duarte P, Ruiz J, Franco G, Safdar N. The effect of process control on the incidence of central venous catheter-associated bloodstream infections and mortality in intensive care units in Mexico. *Crit Care Med*. 2005; 33(9):2022–2027. [PubMed: 16148475]
51. Coopersmith CM, Rebmann TL, Zack JE, et al. Effect of an education program on decreasing catheter-related bloodstream infections in the surgical intensive care unit. *Crit Care Med*. 2002; 30(1):59–64. [PubMed: 11902288]
52. Coopersmith CM, Zack JE, Ward MR, et al. The impact of bedside behavior on catheter-related bacteremia in the intensive care unit. *Arch Surg*. 2004; 139(2):131–136. [PubMed: 14769568]
53. 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(8):641–648. [PubMed: 10766683]
54. 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(9218):1864–1868. [PubMed: 10866442]
55. Nehme AE. Nutritional support of the hospitalized patient The team concept. *Jama*. 1980; 243(19):1906–1908. [PubMed: 6767864]
56. Hawes ML. A proactive approach to combating venous depletion in the hospital setting. *J Infus Nurs*. 2007; 30(1):33–44. [PubMed: 17228197]
57. Brunelle D. Impact of a dedicated infusion therapy team on the reduction of catheter-related nosocomial infections. *J Infus Nurs*. 2003; 26(6):362–366. [PubMed: 14624176]
58. Bosma TL, Jewesson PJ. An infusion program resource nurse consult service: our experience in a major Canadian teaching hospital. *J Infus Nurs*. 2002; 25(5):310–315. [PubMed: 12355056]
59. Pierce CA, Baker JJ. A nursing process model: quantifying infusion therapy resource consumption. *J Infus Nurs*. 2004; 27(4):232–244. [PubMed: 15273630]
60. Tomford JW, Hershey CO. The i.v therapy team: impact on patient care and costs of hospitalization. *NITA*. 1985; 8(5):387–389. [PubMed: 3850385]

61. 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(9):867–874. [PubMed: 10478694]
62. van de Wetering MD, van Woensel JB. Prophylactic antibiotics for preventing early central venous catheter Gram positive infections in oncology patients. *Cochrane Database Syst Rev*. 2007; (1) CD003295.
63. 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(1): 165–171. [PubMed: 9440585]
64. National Kidney Foundation. NKF-K/DOQI clinical practice guidelines for vascular access: update 2000. *American Journal of Kidney Diseases*. 2001; 37:S137–S181. [PubMed: 11229969]
65. Clark-Christoff N, Watters VA, Sparks W, Snyder P, Grant JP. Use of triple-lumen subclavian catheters for administration of total parenteral nutrition. *JPEN J Parenter Enteral Nutr*. 1992; 16(5):403–407. [PubMed: 1433771]
66. 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(1):34–36. [PubMed: 2300831]
67. 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(4):667–672. [PubMed: 3400662]
68. Yeung C, May J, Hughes R. Infection rate for single lumen v triple lumen subclavian catheters. *Infect Control Hosp Epidemiol*. 1988; 9(4):154–158. [PubMed: 3129491]
69. Pronovost P, Needham D, Berenholtz S, et al. An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med*. 2006; 355(26):2725–2732. [PubMed: 17192537]
70. Berenholtz SM, Pronovost PJ, Lipsett PA, et al. Eliminating catheter-related bloodstream infections in the intensive care unit. *Crit Care Med*. 2004; 32(10):2014–2020. [PubMed: 15483409]
71. 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(16):1829–1832. [PubMed: 8053750]
72. Lederle FA, Parenti CM, Berskow LC, Ellingson KJ. The idle intravenous catheter. *Ann Intern Med*. 1992; 116(9):737–738. [PubMed: 1558345]
73. Parenti JJ, Thirion M, Megarbane B, et al. Femoral vs jugular venous catheterization and risk of nosocomial events in adults requiring acute renal replacement therapy: a randomized controlled trial. *Jama*. 2008; 299(20):2413–2422. [PubMed: 18505951]
74. Moretti EW, Ofstead CL, Kristy RM, Wetzler HP. Impact of central venous catheter type and methods on catheter-related colonization and bacteraemia. *J Hosp Infect*. 2005; 61(2):139–145. [PubMed: 16026898]
75. Nagashima G, Kikuchi T, Tsuyuzaki H, et al. To reduce catheter-related bloodstream infections: is the subclavian route better than the jugular route for central venous catheterization? *J Infect Chemother*. 2006; 12(6):363–365. [PubMed: 17235641]
76. Ruesch S, Walder B, Tramer MR. Complications of central venous catheters: internal jugular versus subclavian access—a systematic review. *Crit Care Med*. 2002; 30(2):454–460. [PubMed: 11889329]
77. Sadoyama G, Gontijo FPP. Comparison between the jugular and subclavian vein as insertion site for central venous catheters: microbiological aspects and risk factors for colonization and infection. *Braz J Infect Dis*. 2003; 7(2):142–148. [PubMed: 12959686]
78. 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. [PubMed: 9437382]

79. 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. [PubMed: 2254429]
80. Safdar N, Kluger DM, Maki DG. A review of risk factors for catheter-related bloodstream infection caused by percutaneously inserted, noncuffed central venous catheters: implications for preventive strategies. *Medicine (Baltimore).* 2002; 81(6):466–479. [PubMed: 12441903]
81. Lorente L, Jimenez A, Iribarren JL, Jimenez JJ, Martin MM, Mora ML. The micro-organism responsible for central venous catheter related bloodstream infection depends on catheter site. *Intensive Care Med.* 2006; 32(9):1449–1450. [PubMed: 16804728]
82. Traore O, Liotier J, Souweine B. Prospective study of arterial and central venous catheter colonization and of arterial- and central venous catheter-related bacteremia in intensive care units. *Crit Care Med.* 2005; 33(6):1276–1280. [PubMed: 15942344]
83. Joynt 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(1):178–183. [PubMed: 10631217]
84. 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(12):1118–1121. [PubMed: 9408426]
85. Merrer J, De JB, Golliot F, et al. Complications of femoral and subclavian venous catheterization in critically ill patients: a randomized controlled trial. *Jama.* 2001; 286(6):700–707. [PubMed: 11495620]
86. 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(11):842–845. [PubMed: 9831940]
87. 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(11):1225–1228. [PubMed: 7763129]
88. 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(1):52–59. [PubMed: 8001386]
89. Lorente L, Henry C, Martin MM, Jimenez A, Mora ML. Central venous catheter-related infection in a prospective and observational study of 2,595 catheters. *Crit Care.* 2005; 9(6):R631–R635. [PubMed: 16280064]
90. Schillinger F, Schillinger D, Montagnac R, Milcent T. Post catheterisation vein stenosis in haemodialysis: comparative angiographic study of 50 subclavian and 50 internal jugular accesses. *Nephrol Dial Transplant.* 1991; 6(10):722–724. [PubMed: 1754109]
91. Cimochowski 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(2):154–161. [PubMed: 2314526]
92. Barrett N, Spencer S, McIvor J, Brown EA. Subclavian stenosis: a major complication of subclavian dialysis catheters. *Nephrol Dial Transplant.* 1988; 3(4):423–425. [PubMed: 3140128]
93. 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(1):89–93. [PubMed: 11012428]
94. Breschan C, Platzner M, Jost R, Schaumberger F, Stettner H, Likar R. Comparison of catheter-related infection and tip colonization between internal jugular and subclavian central venous catheters in surgical neonates. *Anesthesiology.* 2007; 107(6):946–953. [PubMed: 18043063]
95. Deshpande KS, Hatem C, Ulrich HL, et al. The incidence of infectious complications of central venous catheters at the subclavian, internal jugular, and femoral sites in an intensive care unit population. *Crit Care Med.* 2005; 33(1):13–20. discussion 234–5. [PubMed: 15644643]
96. Durbec O, Viviani 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(12):1986–1989. [PubMed: 9403747]
97. Venkataraman ST, Thompson AE, Orr RA. Femoral vascular catheterization in critically ill infants and children. *Clin Pediatr (Phila).* 1997; 36(6):311–319. [PubMed: 9196229]

98. Sheridan RL, Weber JM. Mechanical and infectious complications of central venous cannulation in children: lessons learned from a 10-year experience placing more than 1000 catheters. *J Burn Care Res.* 2006; 27(5):713–718. [PubMed: 16998405]
99. 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. [PubMed: 2791583]
100. Goldstein AM, Weber JM, Sheridan RL. Femoral venous access is safe in burned children: an analysis of 224 catheters. *J Pediatr.* 1997; 130(3):442–446. [PubMed: 9063422]
101. Ramos GE, Bolgiani AN, Patino O, et al. Catheter infection risk related to the distance between insertion site and burned area. *J Burn Care Rehabil.* 2002; 23(4):266–271. [PubMed: 12142579]
102. 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. [PubMed: 9878638]
103. Brun-Buisson C, Doyon F, Sollet JP, Cochard JF, Cohen Y, Nitenberg G. Prevention of intravascular catheter-related infection with newer chlorhexidine-silver sulfadiazine-coated catheters: a randomized controlled trial. *Intensive Care Med.* 2004; 30(5):837–843. [PubMed: 15060765]
104. Ostendorf T, Meinhold A, Harter C, et al. Chlorhexidine and silver-sulfadiazine coated central venous catheters in haematological patients--a double-blind, randomised, prospective, controlled trial. *Support Care Cancer.* 2005; 13(12):993–1000. [PubMed: 15834740]
105. Rupp ME, Lisco SJ, Lipsett PA, et al. Effect of a second-generation venous catheter impregnated with chlorhexidine and silver sulfadiazine on central catheter-related infections: a randomized, controlled trial. *Ann Intern Med.* 2005; 143(8):570–580. [PubMed: 16230723]
106. Hanna H, Benjamin R, Chatzinikolaou I, et al. Long-term silicone central venous catheters impregnated with minocycline and rifampin decrease rates of catheter-related bloodstream infection in cancer patients: a prospective randomized clinical trial. *J Clin Oncol.* 2004; 22(15):3163–3171. [PubMed: 15284269]
107. Chelliah A, Heydon KH, Zaoutis TE, et al. Observational trial of antibiotic-coated central venous catheters in critically ill pediatric patients. *Pediatr Infect Dis J.* 2007; 26(9):816–820. [PubMed: 17721377]
108. Raad I, Darouiche R, Dupuis J, et al. Central venous catheters coated with minocycline and rifampin for the prevention of catheter-related colonization and bloodstream infections. A randomized double-blind trial. The Texas Medical Center Catheter Study Group. *Ann Intern Med.* 1997; 127(4):267–274. [PubMed: 9265425]
109. Bhutta A, Gilliam C, Honeycutt M, et al. Reduction of bloodstream infections associated with catheters in paediatric intensive care unit: stepwise approach. *BMJ.* 2007; 334(7589):362–365. [PubMed: 17303886]
110. 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. *Journal of the American Medical Association.* 1999; 281:261–267. [PubMed: 9918482]
111. Maki DG, Stolz SM, Wheeler S, Mermel LA. catheter Prevention of central venous catheter-related bloodstream infection by use of an antiseptic-impregnated A randomized, controlled trial. *Ann Intern Med.* 1997; 127(4):257–266. [PubMed: 9265424]
112. 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(5):1535–1538. [PubMed: 11302823]
113. Oda T, Hamasaki J, Kanda N, Mikami K. Anaphylactic shock induced by an antiseptic-coated central venous [correction of nervous] catheter. *Anesthesiology.* 1997; 87(5):1242–1244. [PubMed: 9366479]
114. Pittaway A, Ford S. Allergy to chlorhexidine-coated central venous catheters revisited. *Br J Anaesth.* 2002; 88(2):304–305. author reply 5. [PubMed: 11878670]
115. Stephens R, Mythen M, Kallis P, Davies DW, Egner W, Rickards A. Two episodes of life-threatening anaphylaxis in the same patient to a chlorhexidine-sulphadiazine-coated central venous catheter. *Br J Anaesth.* 2001; 87(2):306–308. [PubMed: 11493510]

116. Terazawa E, Shimonaka H, Nagase K, Masue T, Dohi S. Severe anaphylactic reaction due to a chlorhexidine-impregnated central venous catheter. *Anesthesiology*. 1998; 89(5):1296–1298. [PubMed: 9822040]
117. Jee R, Nel L, Gnanakumaran G, Williams A, Eren E. Four cases of anaphylaxis to chlorhexidine impregnated central venous catheters: a case cluster or the tip of the iceberg? *Br J Anaesth*. 2009; 103(4):614–615. [PubMed: 19749118]
118. Tambe SM, Sampath L, Modak SM. In vitro evaluation of the risk of developing bacterial resistance to antiseptics and antibiotics used in medical devices. *J Antimicrob Chemother*. 2001; 47(5):589–598. [PubMed: 11328769]
119. Sampath LA, Tambe SM, Modak SM. In vitro and in vivo efficacy of catheters impregnated with antiseptics or antibiotics: evaluation of the risk of bacterial resistance to the antimicrobials in the catheters. *Infect Control Hosp Epidemiol*. 2001; 22(10):640–646. [PubMed: 11776351]
120. Hagau N, Studniska D, Gavrus RL, Csipak G, Hagau R, Slavcovic AV. Central venous catheter colonization and catheter-related bloodstream infections in critically ill patients: a comparison between standard and silver-integrated catheters. *Eur J Anaesthesiol*. 2009; 26(9):752–758. [PubMed: 19384234]
121. Bong JJ, Kite P, Wilco MH, McMahon MJ. Prevention of catheter related bloodstream infection by silver iontophoretic central venous catheters: a randomised controlled trial. *J Clin Pathol*. 2003; 56(10):731–735. [PubMed: 14514774]
122. Corral L, Nolla-Salas M, Ibanez-Nolla J, et al. A prospective, randomized study in critically ill patients using the Oligon Vantex catheter. *J Hosp Infect*. 2003; 55(3):212–219. [PubMed: 14572489]
123. Ranucci M, Isgro G, Giomarelli PP, et al. Impact of oligon central venous catheters on catheter colonization and catheter-related bloodstream infection. *Crit Care Med*. 2003; 31(1):52–59. [PubMed: 12544993]
124. 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. [PubMed: 8207189]
125. Carrer S, Bocchi A, Bortolotti M, et al. Effect of different sterile barrier precautions and central venous catheter dressing on the skin colonization around the insertion site. *Minerva Anestesiol*. 2005; 71(5):197–206. [PubMed: 15834348]
126. Mermel LA, Maki DG. Infectious complications of Swan-Ganz pulmonary artery catheters. Pathogenesis, epidemiology, prevention, and management. *Am J Respir Crit Care Med*. 1994; 149(4 Pt 1):1020–1036. [PubMed: 8143037]
127. Abi-Said D, Raad I, Umphrey J, et al. Infusion therapy team and dressing changes of central venous catheters. *Infect Control Hosp Epidemiol*. 1999; 20(2):101–105. [PubMed: 10064212]
128. Capdevila JA, Segarra A, Pahissa A. Catheter-related bacteremia in patients undergoing hemodialysis. *Ann Intern Med*. 1998; 128(7):600. [PubMed: 9518412]
129. 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. [PubMed: 1677698]
130. 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(11):1818–1823. [PubMed: 8917031]
131. Humar A, Ostromecki A, Drenfeld J, et al. Prospective randomized trial of 10% povidone-iodine versus 0.5% tincture of chlorhexidine as cutaneous antisepsis for prevention of central venous catheter infection. *Clinical infectious diseases : an official publication of the Infectious Diseases Society of America*. 2000; 31(4):1001–1007. [PubMed: 11049783]
132. Chaiyakunapruk N, Veenstra DL, Lipsky BA, Saint S. Chlorhexidine compared with povidone-iodine solution for vascular catheter-site care: a meta-analysis. *Ann Intern Med*. 2002; 136(11):792–801. [PubMed: 12044127]
133. Chaiyakunapruk N, Veenstra DL, Lipsky BA, Sullivan SD, Saint S. Vascular catheter site care: the clinical and economic benefits of chlorhexidine gluconate compared with povidone iodine. *Clin Infect Dis*. 2003; 37(6):764–771. [PubMed: 12955636]

134. Parienti JJ, du Cheyron D, Ramakers M, et al. Alcoholic povidone-iodine to prevent central venous catheter colonization: A randomized unit-crossover study. *Crit Care Med*. 2004; 32(3): 708–713. [PubMed: 15090951]
135. 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(11):1729–1737. [PubMed: 7956275]
136. 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(9):618–620. [PubMed: 10501261]
137. 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(4):187–191. [PubMed: 9849245]
138. Rasero L, Degl'Innocenti M, Mocali M, et al. [Comparison of two different protocols on change of medication in central venous catheterization in patients with bone marrow transplantation: results of a randomized multicenter study]. *Assist Inferm Ric*. 2000; 19(2):112–119. [PubMed: 11107366]
139. 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(3):189–193. [PubMed: 8586787]
140. Flowers RH 3rd, 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(6):878–883. [PubMed: 2492354]
141. Robbins J, Cromwell P, Korones DN. Swimming and central venous catheter-related infections in the child with cancer. *J Pediatr Oncol Nurs*. 1999; 16(1):51–56. [PubMed: 9989017]
142. Howell PB, Walters PE, Donowitz GR, Farr BM. Risk factors for infection of adult patients with cancer who have tunnelled central venous catheters. *Cancer*. 1995; 75(6):1367–1375. [PubMed: 7882288]
143. Ivy DD, Calderbank M, Wagner BD, et al. Closed-hub systems with protected connections and the reduction of risk of catheter-related bloodstream infection in pediatric patients receiving intravenous prostanoid therapy for pulmonary hypertension. *Infect Control Hosp Epidemiol*. 2009; 30(9):823–829. [PubMed: 19637961]
144. Timsit JF, Schwebel C, Bouadma L, et al. Chlorhexidine-impregnated sponges and less frequent dressing changes for prevention of catheter-related infections in critically ill adults: a randomized controlled trial. *Jama*. 2009; 301(12):1231–1241. [PubMed: 19318651]
145. 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(15):2072–2076. [PubMed: 1532429]
146. Gillies D, O'Riordan E, Carr D, O'Brien I, Frost J, Gunning R. Central venous catheter dressings: a systematic review. *J Adv Nurs*. 2003; 44(6):623–632. [PubMed: 14651685]
147. Yamamoto AJ, Solomon JA, Soulen MC, et al. Sutureless securement device reduces complications of peripherally inserted central venous catheters. *Journal of Vascular and Interventional Radiology*. 2002; 13(1):77–81. [PubMed: 11788698]
148. Maki DG, Band JD. A comparative study of polyantibiotic and iodophor ointments in prevention of vascular catheter-related infection. *Am J Med*. 1981; 70(3):739–744. [PubMed: 6259941]
149. Fukunaga A, Naritaka H, Fukaya R, Tabuse M, Nakamura T. Povidone-iodine ointment and gauze dressings associated with reduced catheter-related infection in seriously ill neurosurgical patients. *Infect Control Hosp Epidemiol*. 2004; 25(8):696–698. [PubMed: 15357164]
150. Johnson DW, MacGinley R, Kay TD, et al. A randomized controlled trial of topical exit site mupirocin application in patients with tunnelled, cuffed haemodialysis catheters. *Nephrol Dial Transplant*. 2002; 17(10):1802–1807. [PubMed: 12270988]
151. Fong IW. Prevention of haemodialysis and peritoneal dialysis catheter related infection by topical povidone-iodine. *Postgrad Med J*. 1993; 69(Suppl 3):S15–S17. [PubMed: 8290450]

152. 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. [PubMed: 1762298]
153. 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(9):1591–1597. [PubMed: 2202792]
154. 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(1):147–151. [PubMed: 7608801]
155. 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(9):2200–2204. [PubMed: 10471564]
156. Jurewitsch B, Lee T, Park J, Jeejeebhoy K. Taurolidine 2% as an antimicrobial lock solution for prevention of recurrent catheter-related bloodstream infections. *JPEN J Parenter Enteral Nutr.* 1998; 22(4):242–244. [PubMed: 9661127]
157. 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(6):1269–1278. [PubMed: 10715297]
158. Daghistani D, Horn M, Rodriguez Z, Schoenike S, Toledano S. Prevention of indwelling central venous catheter sepsis. *Med Pediatr Oncol.* 1996; 26(6):405–408. [PubMed: 8614377]
159. Barriga FJ, Varas M, Potin M, et al. Efficacy of a vancomycin solution to prevent bacteremia associated with an indwelling central venous catheter in neutropenic and non-neutropenic cancer patients. *Med Pediatr Oncol.* 1997; 28(3):196–200. [PubMed: 9024516]
160. Dogra GK, Herson H, Hutchison B, et al. Prevention of tunneled hemodialysis catheter-related infections using catheter-restricted filling with gentamicin and citrate: a randomized controlled study. *J Am Soc Nephrol.* 2002; 13(8):2133–2139. [PubMed: 12138146]
161. Allon M. Prophylaxis against dialysis catheter-related bacteremia with a novel antimicrobial lock solution. *Clin Infect Dis.* 2003; 36(12):1539–1544. [PubMed: 12802753]
162. McIntyre CW, Hulme LJ, Taal M, Fluck RJ. Locking of tunneled hemodialysis catheters with gentamicin and heparin. *Kidney Int.* 2004; 66(2):801–805. [PubMed: 15253736]
163. Betjes MG, van Agteren M. Prevention of dialysis catheter-related sepsis with a citrate-taurolidine-containing lock solution. *Nephrol Dial Transplant.* 2004; 19(6):1546–1551. [PubMed: 14993498]
164. Weijmer MC, van den Dorpel MA, Van de Ven PJ, et al. Randomized, clinical trial comparison of trisodium citrate 30% and heparin as catheter-locking solution in hemodialysis patients. *J Am Soc Nephrol.* 2005; 16(9):2769–2777. [PubMed: 16033861]
165. Bleyer AJ, Mason L, Russell G, Raad II, Sherertz RJ. A randomized, controlled trial of a new vascular catheter flush solution (minocycline-EDTA) in temporary hemodialysis access. *Infect Control Hosp Epidemiol.* 2005; 26(6):520–524. [PubMed: 16018426]
166. Kim SH, Song KI, Chang JW, et al. Prevention of uncuffed hemodialysis catheter-related bacteremia using an antibiotic lock technique: a prospective, randomized clinical trial. *Kidney Int.* 2006; 69(1):161–164. [PubMed: 16374438]
167. Al-Hwiesh AK, Abdul-Rahman IS. Successful prevention of tunneled, central catheter infection by antibiotic lock therapy using vancomycin and gentamycin. *Saudi J Kidney Dis Transpl.* 2007; 18(2):239–247. [PubMed: 17496402]
168. Nori US, Manoharan A, Yee J, Besarab A. Comparison of low-dose gentamicin with minocycline as catheter lock solutions in the prevention of catheter-related bacteremia. *Am J Kidney Dis.* 2006; 48(4):596–605. [PubMed: 16997056]
169. Saxena AK, Panhotra BR, Sundaram DS, et al. Tunneled catheters' outcome optimization among diabetics on dialysis through antibiotic-lock placement. *Kidney Int.* 2006; 70(9):1629–1635. [PubMed: 16955110]

170. Lok CE, Stanley KE, Hux JE, Richardson R, Tobe SW, Conly J. Hemodialysis infection prevention with polysporin ointment. *J Am Soc Nephrol.* 2003; 14(1):169–179. [PubMed: 12506149]
171. Yahav D, Rozen-Zvi B, Gaftor-Gvili A, Leibovici L, Gaftor U, Paul M. Antimicrobial lock solutions for the prevention of infections associated with intravascular catheters in patients undergoing hemodialysis: systematic review and meta-analysis of randomized, controlled trials. *Clin Infect Dis.* 2008; 47(1):83–93. [PubMed: 18498236]
172. Labriola L, Crott R, Jadoul M. Preventing haemodialysis catheter-related bacteraemia with an antimicrobial lock solution: a meta-analysis of prospective randomized trials. *Nephrol Dial Transplant.* 2008; 23(5):1666–1672. [PubMed: 18065789]
173. Jaffer Y, Selby NM, Taal MW, Fluck RJ, McIntyre CW. A meta-analysis of hemodialysis catheter locking solutions in the prevention of catheter-related infection. *Am J Kidney Dis.* 2008; 51(2):233–241. [PubMed: 18215701]
174. Fontaine PJ. Performance of a new softening expanding midline catheter in home intravenous therapy patients. *J Intraven Nurs.* 1991; 14(2):91–99. [PubMed: 2005511]
175. 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(4):233–239. [PubMed: 1614749]
176. Mermel LA, Parenteau S, Tow SM. The risk of midline catheterization in hospitalized patients A prospective study. *Ann Intern Med.* 1995; 123(11):841–844. [PubMed: 7486466]
177. 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(10):1073–1079. [PubMed: 2209033]
178. Uldall PR, Merchant N, Woods F, Yarworski U, Vas S. Changing subclavian haemodialysis cannulas to reduce infection. *Lancet.* 1981; 1(8234):1373. [PubMed: 6113344]
179. Cook D, Randolph A, Kernerman P, et al. Central venous catheter replacement strategies: a systematic review of the literature. *Crit Care Med.* 1997; 25(8):1417–1424. [PubMed: 9267959]
180. 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. [PubMed: 1522842]
181. Beathard GA. Management of bacteremia associated with tunneled-cuffed hemodialysis catheters. *J Am Soc Nephrol.* 1999; 10:1045–1049. [PubMed: 10232691]
182. 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(2):321–337. [PubMed: 9540917]
183. Robinson D, Suhocki P, Schwab SJ. Treatment of infected tunneled venous access hemodialysis catheters with guidewire exchange. *Kidney Int.* 1998; 53:1792–1794. [PubMed: 9607214]
184. Saad TF. Bacteremia associated with tunneled, cuffed hemodialysis catheters. *Am J Kidney Dis.* 1999; 34(6):1114–1124. [PubMed: 10585322]
185. Guttmann DM, Trerotola SO, Clark TW, et al. Malfunctioning and infected tunneled infusion catheters: over-the-wire catheter exchange versus catheter removal and replacement. *J Vasc Interv Radiol.* 2011; 22(5):642–646. [PubMed: 21514518]
186. 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(2):282–292. [PubMed: 10676728]
187. Powe NR, Jaar B, Furth SL, Hermann J, Briggs W. Septicemia in dialysis patients: incidence, risk factors, and prognosis. *Kidney Int.* 1999; 55(3):1081–1090. [PubMed: 10027947]
188. Blot F, Chachaty E, Raynard B, Antoun S, Bourgain JL, Nitenberg G. Mechanisms and risk factors for infection of pulmonary artery catheters and introducer sheaths in cancer patients admitted to an intensive care unit. *J Hosp Infect.* 2001; 48(4):289–297. [PubMed: 11461130]