









SHEA/IDSA/APIC Practice Recommendation

Strategies to prevent central line-associated bloodstream infections in acute-care hospitals: 2022 Update

Niccolò Buetti MD, MSc, PhD^{1,2,a} , Jonas Marschall MD, MSc^{3,4,a} , Marci Drees MD, MS^{5,6} ,
Mohamad G. Fakih MD, MPH⁷ , Lynn Hadaway MEd, RN, NPD-BC, CRNI⁸, Lisa L. Maragakis MD, MPH⁹,
Elizabeth Monsees PhD, MBA, RN, CIC^{10,11} , Shannon Novosad MD MPH¹², Naomi P. O’Grady MD¹³,
Mark E. Rupp MD¹⁴ , Joshua Wolf MBBS, PhD, FRACP^{15,16} , Deborah Yokoe MD, MPH¹⁷ and
Leonard A. Mermel DO, ScM^{18,19} 

¹Infection Control Programme, University of Geneva Hospitals and Faculty of Medicine, Geneva, Switzerland, ²University of Paris, Paris, France, ³Department of Infectious Diseases, Bern University Hospital and University of Bern, Bern, Switzerland, ⁴Division of Infectious Diseases, Department of Medicine, Washington University School of Medicine, St. Louis, Missouri, United States, ⁵ChristianaCare, Wilmington, Delaware, United States, ⁶Sidney Kimmel Medical College at Thomas Jefferson University, Philadelphia, Pennsylvania, United States, ⁷Ascension Healthcare and Wayne State University School of Medicine, Detroit, Michigan, United States, ⁸Lynn Hadaway Associates, Milner, Georgia, United States, ⁹Johns Hopkins University School of Medicine, Baltimore, Maryland, United States, ¹⁰Children’s Mercy Hospital, Kansas City, Missouri, United States, ¹¹University of Missouri–Kansas City School of Medicine, Kansas City, Missouri, United States, ¹²Division of Healthcare Quality Promotion, Centers for Disease Control and Prevention, Atlanta, Georgia, United States, ¹³National Institutes of Health, Bethesda, Maryland, United States, ¹⁴University of Nebraska Medical Center, Omaha, Nebraska, United States, ¹⁵Department of Infectious Diseases, St. Jude Children’s Research Hospital, Memphis, Tennessee, United States, ¹⁶Department of Pediatrics, University of Tennessee Health Science Center, Memphis, Tennessee, United States, ¹⁷University of California–San Francisco, San Francisco, California, United States, ¹⁸Warren Alpert Medical School of Brown University, Providence, Rhode Island, United States and ¹⁹Rhode Island Hospital, Providence, Rhode Island, United States

Purpose

Previously published guidelines provide comprehensive recommendations for detecting and preventing healthcare-associated infections (HAIs). The intent of this document is to highlight practical recommendations in a concise format designed to assist acute-care hospitals in implementing and prioritizing their central line-associated bloodstream infection (CLABSI) prevention efforts. This document updates the *Strategies to Prevent Central Line-Associated Bloodstream Infections in Acute-Care Hospitals* published in 2014.¹ This expert guidance document is sponsored by the Society for Healthcare Epidemiology of America (SHEA). It is the product of a collaborative effort led by SHEA, the Infectious Diseases Society of America (IDSA), the Association for Professionals in Infection Control and Epidemiology (APIC), the American Hospital Association (AHA), and The Joint Commission, with major contributions from representatives of a number of organizations and societies with content expertise.

Summary of major changes

This section lists major changes from the *Strategies to Prevent Central Line-Associated Bloodstream Infections in Acute-Care Hospitals: 2014*

Author for correspondence: Dr. Leonard A. Mermel, E-mail: lmermel@lifespan.org

^aAuthors of equal contribution.

Cite this article: Buetti N, et al. (2022). Strategies to prevent central line-associated bloodstream infections in acute-care hospitals: 2022 Update. *Infection Control & Hospital Epidemiology*, 43: 553–569, <https://doi.org/10.1017/ice.2022.87>

© The Author(s), 2022. Published by Cambridge University Press on behalf of The Society for Healthcare Epidemiology of America. This is an Open Access article, distributed under the terms of the Creative Commons Attribution licence (<http://creativecommons.org/licenses/by/4.0/>), which permits unrestricted re-use, distribution and reproduction, provided the original article is properly cited.

Update,¹ including recommendations that have been added, removed, or altered. Recommendations are categorized as essential practices that should be adopted by all acute-care hospitals (in 2014 these were “basic practices,” renamed to highlight their importance as foundational for hospitals’ HAI prevention programs) or additional approaches that can be considered for use in locations and/or populations within hospitals when CLABSIs are not controlled after implementation of essential practices (in 2014 these were “special approaches”). See Table 1 for a complete summary of the recommendations contained in this document.

Essential practices

- The subclavian vein is considered the preferable site for central venous catheter (CVC) insertion in the intensive care setting to reduce infectious complications. Previously, the primary recommendation was to avoid the femoral vein for access. Although this remains valid, it has been replaced by a positively formulated recommendation regarding the subclavian site.
- The recommendation to use ultrasound guidance for catheter insertion is backed by better evidence than was available previously; however, the procedure itself may jeopardize the strict observation of sterile technique.
- The use of chlorhexidine-containing dressings is now considered an “essential practice”; in the past, it was listed under special approaches that should only be employed if CLABSI rates remain high despite the implementation of basic practices.
- Routine replacement of administration sets not used for blood, blood products, or lipid formulations can be performed at

Table 1. Summary of Recommendations to Prevent CLABSI

Essential Practices
<p><i>Before insertion</i></p> <ol style="list-style-type: none"> 1. Provide easy access to an evidence-based list of indications for CVC use to minimize unnecessary CVC placement (Quality of Evidence: LOW) 2. Require education and competency assessment of HCP involved in insertion, care, and maintenance of CVCs about CLABSI prevention (Quality of Evidence: MODERATE)⁷⁴⁻⁷⁸ 3. Bathe ICU patients aged >2 months with a chlorhexidine preparation on a daily basis (Quality of Evidence: HIGH)⁸⁶⁻⁹⁰ <p><i>At insertion</i></p> <ol style="list-style-type: none"> 1. In ICU and non-ICU settings, a facility should have a process in place, such as a checklist, to ensure adherence to infection prevention practices at the time of CVC insertion (Quality of Evidence: MODERATE)¹⁰¹ 2. Perform hand hygiene prior to catheter insertion or manipulation (Quality of Evidence: MODERATE)¹⁰²⁻¹⁰⁷ 3. The subclavian site is preferred to reduce infectious complications when the catheter is placed in the ICU setting (Quality of Evidence: HIGH)^{33,37,108-110} 4. Use an all-inclusive catheter cart or kit (Quality of Evidence: MODERATE)¹¹⁸ 5. Use ultrasound guidance for catheter insertion (Quality of Evidence: HIGH)^{119,120} 6. Use maximum sterile barrier precautions during CVC insertion (Quality of Evidence: MODERATE)¹²³⁻¹²⁸ 7. Use an alcoholic chlorhexidine antiseptic for skin preparation (Quality of Evidence: HIGH)^{42,129-134} <p><i>After insertion</i></p> <ol style="list-style-type: none"> 1. Ensure appropriate nurse-to-patient ratio and limit use of float nurses in ICUs (Quality of Evidence: HIGH)^{34,35} 2. Use chlorhexidine-containing dressings for CVCs in patients over 2 months of age (Quality of Evidence: HIGH)^{45,135-142} 3. For non-tunneled CVCs in adults and children, change transparent dressings and perform site care with a chlorhexidine-based antiseptic at least every 7 days or immediately if the dressing is soiled, loose, or damp. Change gauze dressings every 2 days or earlier if the dressing is soiled, loose, or damp (Quality of Evidence: MODERATE)¹⁴⁵⁻¹⁴⁸ 4. Disinfect catheter hubs, needleless connectors, and injection ports before accessing the catheter (Quality of Evidence: MODERATE)¹⁵⁰⁻¹⁵⁴ 5. Remove nonessential catheters (Quality of Evidence: MODERATE) 6. Routine replacement of administration sets not used for blood, blood products, or lipid formulations can be performed at intervals up to 7 days (Quality of Evidence: HIGH)¹⁶⁴ 7. Perform surveillance for CLABSI in ICU and non-ICU settings (Quality of Evidence: HIGH)^{13,165,166}
Additional Approaches
<ol style="list-style-type: none"> 1. Use antiseptic- or antimicrobial-impregnated CVCs (Quality of Evidence: HIGH in adult patients^{38,39,169-171} and Quality of Evidence: MODERATE in pediatric patients)^{172,173} 2. Use antimicrobial lock therapy for long-term CVCs (Quality of Evidence: HIGH)¹⁷⁷⁻¹⁸⁴ 3. Use recombinant tissue plasminogen activating factor (rt-PA) once weekly after hemodialysis in patients undergoing hemodialysis through a CVC (Quality of Evidence: HIGH)¹⁹² 4. Utilize infusion or vascular access teams for reducing CLABSI rates (Quality of Evidence: LOW)^{193,194} 5. Use antimicrobial ointments for hemodialysis catheter insertion sites (Quality of Evidence: HIGH)¹⁹⁷⁻²⁰¹ 6. Use an antiseptic-containing hub/connector cap/port protector to cover connectors (Quality of Evidence: MODERATE)²⁰²⁻²⁰⁸
Approaches that Should Not Be Considered a Routine Part of CLABSI Prevention
<ol style="list-style-type: none"> 1. Do not use antimicrobial prophylaxis for short-term or tunneled catheter insertion or while catheters are <i>in situ</i> (Quality of Evidence: HIGH)²⁰⁹⁻²¹³ 2. Do not routinely replace CVCs or arterial catheters (Quality of Evidence: HIGH)²¹⁴
Unresolved Issues
<ol style="list-style-type: none"> 1. Routine use of needleless connectors as a CLABSI prevention strategy before an assessment of risks, benefits, and education regarding proper use²¹⁵⁻²¹⁹ 2. Surveillance of other types of catheters (eg, peripheral arterial or peripheral venous catheters)^{11,21,22} 3. Standard, nonantimicrobial transparent dressings and CLABSI risk. 4. The impact of using chlorhexidine-based products on bacterial resistance to chlorhexidine 5. Sutureless securement 6. Impact of silver zeolite-impregnated umbilical catheters in preterm infants (applicable in countries where it is approved for use in children)²²⁷ 7. Necessity of mechanical disinfection of a catheter hub, needleless connector, and injection port before accessing the catheter when antiseptic-containing caps are being used

Note. CLABSI, central line-associated bloodstream infection; CVC, central venous catheter; HCP, healthcare personnel; ICU, intensive care unit.

intervals of up to 7 days. Previously, this interval was no longer than 4 days.

Additional approaches

- Antimicrobial ointment for the catheter site, which is geared toward the population of hemodialysis patients, has been moved to “additional practices” given the focus on a specific population.
- Despite currently being supported by high-level evidence, antiseptic-containing caps remain an “additional practice” because they are not considered superior to the manual disinfection, an essential practice.
- The importance of infusion teams has been highlighted by listing it under “additional practices” (previously considered unresolved).

- Sutureless securement of catheters was not discussed in the previous version of this section.

Intended use

This document was developed following the process outlined in the *Handbook for SHEA-Sponsored Guidelines and Expert Guidance Documents*.² No guideline or expert guidance document can anticipate all clinical situations, and this document is not meant to be a substitute for individual clinical judgment by qualified professionals.

This document is based on a synthesis of evidence, theoretical rationale, current practices, practical considerations, writing-group consensus, and consideration of potential harm, where

Table 2. Quality of Evidence^a

Category	Definition
HIGH	Highly confident that the true effect lies close to that of the estimated size and direction of the effect. Evidence is rated as high quality when there are a wide range of studies with no major limitations, there is little variation between studies, and the summary estimate has a narrow confidence interval.
MODERATE	The true effect is likely to be close to the estimated size and direction of the effect, but there is a possibility that it is substantially different. Evidence is rated as moderate quality when there are only a few studies and some have limitations but not major flaws, there is some variation between studies, and/or the confidence interval of the summary estimate is wide.
LOW	The true effect may be substantially different from the estimated size and direction of the effect. Evidence is rated as low quality when supporting studies have major flaws, there is important variation between studies, the confidence interval of the summary estimate is very wide, and/or there are no rigorous studies.

^aBased on the CDC Healthcare Infection Control Practices Advisory Committee (HICPAC) "Update to the Centers for Disease Control and Prevention and the Healthcare Infection Control Practices Advisory Committee Recommendations Categorization Scheme for Infection Control and Prevention Guideline Recommendations" (October 2019), the Grades of Recommendation, Assessment, Development, and Evaluation (GRADE),²⁶⁵ and the Canadian Task Force on Preventive Health Care.²⁶⁶

applicable. A summary list of recommendations is provided along with their relevant rationales (see Table 1).

Methods

SHEA recruited 3 subject-matter experts in the prevention of CLABSI to lead the panel of members representing the Compendium partnering organizations: SHEA, the Infectious Diseases Society of America (IDSA), the Association for Professionals in Infection Control and Epidemiology (APIC), the American Hospital Association (AHA), and The Joint Commission, as well as representation by the Centers for Disease Control and Prevention (CDC).

SHEA utilized a consultant medical librarian, who worked with each panel to develop a comprehensive search strategy for PubMed and Embase (January 2012–July 2019; updated to August 2021). Articles' abstracts were reviewed by panel members in a double-blind fashion using the abstract management software, Covidence (Melbourne, Australia), and subsequently reviewed as full text. The Compendium Lead Authors group voted to update the literature findings, and the librarian reran the search to update it to August 2021. Panel members reviewed the abstracts of these articles via Covidence and incorporated relevant references.

Recommendations resulting from this literature review process were classified based on the quality of evidence and the balance between desirable and potential for undesirable effects of various interventions (see Table 2). Panel members met via video conference to discuss literature findings; recommendations; quality of evidence for these recommendations; and classification as essential practices, additional approaches, or unresolved issues. Panel members reviewed and approved the document and its recommendations.

The Compendium Expert Panel, made up of members with broad healthcare epidemiology and infection prevention expertise, reviewed the draft manuscript after consensus had been reached by writing panel members.

Following review and approval by the Expert Panel, the 5 partnering organizations, stakeholder organizations, and the CDC reviewed the document. Prior to dissemination, the guidance document was reviewed and approved by the SHEA Guidelines Committee, the IDSA Standards and Practice Guidelines Committee, and the Boards of SHEA, IDSA, APIC, AHA, and The Joint Commission.

All panel members complied with SHEA and IDSA policies on conflict-of-interest disclosure.

Section 1: Rationale and statements of concern

Burden of outcomes associated with hospital-acquired CLABSI

1. Increased length of hospital stay^{3–6}
2. Increased cost. The adjusted variable costs for patients with CLABSI were \$32,000 (2010 US dollars) higher on average than for patients without CLABSI⁷
3. Increased morbidity and mortality⁸

Risk factors for CLABSI

1. Patients at risk for CLABSI in acute-care facilities are those with a CVC in place:
 - a. Intensive care unit (ICU) population: The risk of CLABSI in ICU patients is high. Reasons for this include the frequent insertion of multiple catheters^{9,10}; the use of specific types of catheters that are almost exclusively inserted in ICU patients and associated with substantial risk (eg, pulmonary artery catheters with catheter introducers); and the fact that catheters are frequently placed in emergency circumstances, repeatedly accessed each day, and often needed for extended periods.^{11,12}
 - b. Non-ICU population: Although the primary focus of attention over the last 20 years has been the ICU setting, most CLABSIs occur in hospital units outside the ICU or in outpatients.^{13–17}
2. Infection prevention and control efforts should include other vulnerable populations such as patients receiving hemodialysis through catheters,¹⁸ intraoperative patients,¹⁹ and oncology patients.²⁰
3. In addition to CVCs, short-term peripheral catheters,²¹ peripherally inserted central venous catheters (PICCs), midline catheters, and peripheral arterial catheters also carry a risk of infection.²²
4. Independent risk factors for CLABSI (in at least 2 published studies)^{23–45}
 - a. Prolonged hospitalization before catheterization
 - b. Prolonged duration of catheterization
 - c. Heavy microbial colonization at insertion site
 - d. Heavy microbial colonization of the catheter hub
 - e. Multilumen catheters

- f. Concurrent catheters
- g. Neutropenia
- h. Body mass index (BMI) >40
- i. Prematurity (ie, early gestational age)
- j. Reduced nurse-to-patient ratio in the ICU
- k. Parenteral nutrition
 - l. Substandard catheter care (eg, excessive manipulation of the catheter)
- m. Transfusion of blood products (in children)

Section 2: Background on detection of CLABSI

Surveillance methods and definitions for CLABSI

1. Use consistent surveillance methods and definitions to allow comparison to benchmark data.
2. Refer to the *National Healthcare Safety Network (NHSN) Patient Safety Component Manual* for information on the appropriate surveillance methodology, including information about blood specimen collection and surveillance definitions of CLABSIs. The relevant chapter of the manual is “Chapter 4: Bloodstream Infection Event (Central Line-Associated Bloodstream Infection and Non-Central Line-Associated Bloodstream Infection).”⁴⁶
 - a. Recent data suggest that interrater reliability using NHSN definitions is lower than expected.^{47–50} This may also affect the reliability of public reporting.
 - b. The NHSN surveillance definition for CLABSI is different than the clinical definition for catheter-related bloodstream infection (CRBSI). The latter is subject to various factors (eg, laboratory capabilities, catheter removal, and submitting the catheter tip for culture).⁵¹ The evidence presented here includes studies that used either CLABSI or CRBSI as an outcome measure and the lesser accuracy of CLABSI may impact the validity of the evidence.

Section 3: Background on prevention of CLABSI

Summary of existing guidelines and recommendations

1. Several governmental, public health, and professional organizations have published evidence-based guidelines and/or implementation aids regarding the prevention of CLABSI including the following:
 - a. Healthcare Infection Control Practices Advisory Committee (HICPAC), Centers for Disease Control and Prevention (CDC)^{52,53}
 - b. Institute for Healthcare Improvement (IHI)⁵⁴
 - c. Agency for Healthcare Research and Quality, *Making Health Care Safer*⁵⁵
 - d. American Pediatric Surgical Association, *Outcomes and Clinical Trials Committee*⁵⁶
 - e. The Joint Commission⁵⁷
 - f. APIC, *Implementation Guide to Preventing Central Line-Associated Bloodstream Infections*⁵⁸
 - g. Infusion Nurses Society, *Infusion Nursing Standards of Practice*⁵⁹
2. The recommendations in this document focus on CVCs unless noted otherwise. These recommendations:
 - a. Are not stratified based on the type of catheter (eg, tunneled, implanted, cuffed, non-cuffed catheter, dialysis catheter).

- b. May not be applicable in their entirety for prevention of bloodstream infections with other intravascular devices.

Infrastructure requirements

Facilities undertaking CLABSI interventions should have the following elements in place:

1. An adequately staffed infection prevention and control program responsible for identifying patients who meet the surveillance definition for CLABSI.
2. Infection prevention staff and, preferably, information technology support to collect and calculate catheter days as a denominator when computing rates of CLABSI and patient days to allow calculation of CVC utilization. Catheter days from information systems should be validated against a manual method, with a margin of error no greater than $\pm 5\%$.^{60–62}
3. Resources to provide appropriate education and training.
4. Adequate laboratory support for timely processing of specimens and reporting of results, as specified by the supervisor of the surveillance program.

Section 4: Recommended strategies to prevent CLABSI

Recommendations are categorized as either (1) essential practices that should be adopted by all acute-care hospitals or (2) additional approaches that can be considered in locations and/or populations within hospitals when CLABSIs are not controlled by use of essential practices. Essential practices include recommendations in which the potential to affect CLABSI risk clearly outweighs the potential for undesirable effects. Additional approaches include recommendations in which the intervention is likely to reduce CLABSI risk but there is concern about the risks for undesirable outcomes, recommendations for which the quality of evidence is low, recommendations in which cost-to-benefit ratio may be high, or recommendations in which evidence supports the impact of the intervention in select settings (eg, during outbreaks) or for select patient populations. Hospitals can prioritize their efforts by initially focusing on implementation of the prevention strategies listed as essential practices. If CLABSI surveillance or other risk assessments suggest ongoing opportunities for improvement, hospitals should consider adopting some or all of the prevention approaches listed as additional approaches. These can be implemented in specific locations or patient populations or can be implemented hospital-wide, depending on outcome data, risk assessment, and/or local requirements. Each infection prevention recommendation is given a quality of evidence grade (see Table 2).

Essential practices for preventing CLABSI recommended for all acute-care hospitals

Some of the following measures have been combined into a “prevention bundle” that focuses on catheter insertion.^{63,64} Numerous studies have documented that use of such bundles is effective, sustainable, and cost-effective in both adults and children.^{63,65–68} Bundles are most likely to be successful if implemented in a previously established patient safety culture and their success depends on adherence to individual measures.⁶⁹ However, data suggests that not all components of bundles may be necessary to achieve

an effect on CLABSI rates.⁷⁰ After catheter insertion, maintenance bundles have been proposed to ensure optimal catheter care.⁷¹ More data are needed to determine which components of the maintenance bundle are essential in reducing risk.^{72,73}

Before insertion

1. **Provide easy access to an evidence-based list of indications for CVC use to minimize unnecessary CVC placement** (Quality of Evidence: LOW)
2. **Require education and competency assessment of healthcare personnel (HCP) involved in insertion, care, and maintenance of CVCs about CLABSI prevention** (Quality of Evidence: MODERATE)^{74–78}
 - a. Include the indications for catheter use, appropriate insertion and maintenance, the risk of CLABSI, and general infection prevention strategies.
 - b. Ensure that all HCP involved in catheter insertion and maintenance complete an educational program on essential practices to prevent CLABSI before performing these duties.^{79,80} Periodic retraining with a competency assessment may be of benefit.⁸¹
 - c. Periodically assess HCP knowledge of and adherence to preventive measures.
 - d. Require all HCP who insert a CVC to undergo a credentialing process (as established by the individual healthcare institution) to ensure their competency before independently inserting a CVC and aseptic technique for accessing and maintaining the CVC thereafter.
 - e. Re-educate when an institution changes components of the infusion system that requires a change in practice (eg, when an institution's change of the needleless connector requires a change in nursing practice).
 - f. Use simulation training for proper catheter insertion and maintenance if available.^{82–85}
3. **Bathe ICU patients >2 months of age with a chlorhexidine preparation on a daily basis** (Quality of Evidence: HIGH)^{86–90}
 - a. In long-term acute-care hospitals (LTACHs), daily chlorhexidine bathing may also be considered as a preventive measure.⁹¹
 - b. The role of chlorhexidine bathing in non-ICU patients remains unclear.^{92,93} One cluster-randomized study found a significant reduction in device-associated bacteremia with CHG bathing in this patient population⁹³; however, some of these patients also received methicillin-resistant *Staphylococcus aureus* (MRSA) decolonization, making it difficult to draw firm conclusions regarding CHG bathing alone. Several studies have suggested benefit among adult hematology-oncology patients; however, a similar reduction was not observed for pediatric patients with similar conditions.^{94,95} Accordingly, potential benefits and risks, such as increases in resistance and cost, need to be carefully considered.
 - c. The safety and efficacy of routine use of chlorhexidine bathing in infants <2 months of postnatal age remains unclear.⁹⁶ Although life-threatening skin injuries from CHG have been reported in very young or very preterm infants, they typically occur in infants with a birthweight

<1,000 g who are <7 days postnatal age, and they appear rare in older infants.^{97–99}

- d. Widespread use of chlorhexidine may be associated with decreased chlorhexidine susceptibility, although the clinical relevance of this finding is not well defined.¹⁰⁰

At insertion

1. **In ICU and non-ICU settings, a facility should have a process in place, such as a checklist, to ensure adherence to infection prevention practices at the time of CVC insertion** (Quality of Evidence: MODERATE)¹⁰¹
 - a. Ensure and document adherence to aseptic technique
 - i. Checklists have been suggested to ensure optimal insertion practices. If used, the documentation should be done by someone other than the inserter.
 - ii. Observation of CVC insertion should be done by a nurse, physician, or other HCP who has received appropriate education (see above) to ensure that aseptic technique is maintained.
 - iii. HCP should be empowered to stop the procedure if breaches in aseptic technique are observed.
2. **Perform hand hygiene prior to catheter insertion or manipulation** (Quality of Evidence: MODERATE)^{102–107}
 - a. Use an alcohol-based waterless product or soap and water.
 - i. Use of gloves does not obviate hand hygiene.
3. **The subclavian site is preferred to reduce infectious complications when the catheter is placed in the ICU setting** (Quality of Evidence: HIGH)^{33,37,108–110}
 - a. In the non-ICU setting, the risk of infection between the different sites remains unclear. Importantly, in emergent settings, ensuring life-saving vascular access in the fastest possible way may determine the choice of access site.
 - b. In children and infants, femoral vein catheterization may be considered if upper body sites are contraindicated.¹¹¹ Tunneled femoral vein catheters, with an exit site outside the diaper area in the mid-thigh, may be safer and provide additional risk reduction.^{112,113}
 - c. Controversy exists regarding infectious and noninfectious complications associated with different short-term CVC access sites.³³ The risk and benefit of different insertion sites must be considered on an individual basis with regard to infectious and noninfectious complications.³³ Among others, this applies to patients currently receiving or likely to require hemodialysis in whom the subclavian site is avoided due to risk of stenosis.
 - d. Do not use peripherally inserted central venous catheters (PICCs) as a strategy to reduce the risk of CLABSI. Risk of infection with PICCs in hospitalized patients approaches that of other CVCs.¹¹⁴ However, the majority of CLABSIs due to PICCs occur in non-ICU settings.¹¹⁵
 - e. Midline catheters are increasingly being used as an alternative to CVCs for short-term vascular access, with some observational studies suggesting lower bloodstream infection risk associated with midline catheters versus PICCs¹¹⁶ and versus CVCs,¹¹⁷ respectively. Randomized controlled trials comparing the risk of bloodstream infections and other complications associated with these devices are needed.

4. **Use an all-inclusive catheter cart or kit** (Quality of Evidence: MODERATE)¹¹⁸
 - a. A catheter cart or kit that contains all necessary components for aseptic catheter insertion should be available and easily accessible in all units where CVCs are inserted.
 5. **Use ultrasound guidance for catheter insertion** (Quality of Evidence: HIGH)^{119,120}
 - a. Ultrasound-guided internal jugular and femoral vein catheterization reduces the risk of noninfectious complications associated with CVC placement¹²¹ but the use of ultrasound may lead to a breach in aseptic technique.¹²²
 - b. It is unclear whether ultrasound-guided subclavian vein insertion reduces risk of infectious complications.
 6. **Use maximum sterile barrier precautions during CVC insertion** (Quality of Evidence: MODERATE)^{123–128}
 - a. Use maximum sterile barrier precautions:
 - i. A mask, cap, sterile gown, and sterile gloves are to be worn by all HCP involved in the catheter insertion procedure.
 - ii. The patient is to be covered with a large (“full-body”) sterile drape during catheter insertion.
 - b. These measures should also be followed when exchanging a catheter over a guidewire.
 - c. A prospective, randomized study in surgical patients showed no additional benefit for maximum sterile barrier precautions¹²⁶; nevertheless, most available evidence suggests risk reduction with this intervention.
 7. **Use an alcoholic chlorhexidine antiseptic for skin preparation** (Quality of Evidence: HIGH)^{42,129–134}
 - a. Before catheter insertion, apply an alcoholic chlorhexidine solution containing at least 2% chlorhexidine gluconate to the insertion site.
 - i. The antiseptic solution must be allowed to dry before making the skin puncture.
 - ii. Alcoholic chlorhexidine for skin antisepsis to prevent CLABSI in NICU patients should be used when the benefits are judged to outweigh potential risk.
- dressing is soiled, loose, or damp. Change gauze dressings every 2 days or earlier if the dressing is soiled, loose, or damp.** (Quality of Evidence: MODERATE)^{145–148}
- a. Less frequent, clinically indicated dressing changes may be used for NICU patients or others at high risk of serious complications from catheter dislodgement.¹⁴⁹
 - b. If there is excessive bleeding or drainage from the catheter exit site, use gauze dressings instead of transparent dressings until drainage resolves.
4. **Disinfect catheter hubs, needleless connectors, and injection ports before accessing the catheter** (Quality of Evidence: MODERATE)^{150–154}
 - a. Before accessing catheter hubs, needleless connectors, or injection ports, vigorously apply mechanical friction with an alcoholic chlorhexidine preparation, or 70% alcohol. Alcoholic chlorhexidine may have additional residual activity compared to alcohol for this purpose and is therefore preferred.¹⁵⁵
 - b. Apply mechanical friction for a minimum of 5 seconds to reduce contamination.^{156,157} It is unclear whether this duration of disinfection can be generalized to needleless connectors not tested in these studies.
 - c. Monitor compliance with hub-connector-port disinfection because approximately half of such catheter components are colonized under conditions of standard practice.^{152,156,158}
 5. **Remove nonessential catheters** (Quality of Evidence: MODERATE)
 - a. Assess the need for continued intravascular access on a daily basis during multidisciplinary rounds. Remove catheters not required for patient care. Decreasing CVC utilization reduces CRBSI risk.¹⁵⁹ However, reducing CVC utilization may result in increased use of other intravascular catheters with corresponding infection risk.
 - b. Audits to determine whether CVCs are routinely removed after their intended use may be helpful.^{160,161} Both simple and multifaceted interventions are effective at reducing unnecessary CVC use.^{162,163}
 6. **Routine replacement of administration sets not used for blood, blood products, or lipid formulations can be performed at intervals up to 7 days** (Quality of Evidence: HIGH)¹⁶⁴
 - a. The optimal replacement of intermittently used administration sets is unresolved.
 7. **Perform surveillance for CLABSI in ICU and non-ICU settings** (Quality of Evidence: HIGH)^{13,165,166}
 - a. Measure unit-specific incidence of CLABSI (eg, CLABSI per 1,000 catheter days) and report the data on a regular basis to the units, physician and nursing leadership, and hospital administrators overseeing the units.
 - b. Compare CLABSI incidence to historical data for individual units and to national rates (ie, NHSN).¹⁶⁷
 - c. Audit surveillance as necessary to minimize variation in interobserver reliability.^{48,168}

After insertion

1. **Ensure appropriate nurse-to-patient ratio and limit use of float nurses in ICUs** (Quality of Evidence: HIGH)^{34,35}
 - a. Observational studies suggest that an adequate nurse-to-patient ratio must be maintained in ICUs where nurses are managing patients with CVCs and that the number of float nurses working in the ICU environment should be minimized.
2. **Use chlorhexidine-containing dressings for CVCs in patients over 2 months of age** (Quality of Evidence: HIGH)^{45,135–142}
 - a. It is unclear whether there is additional benefit with use of a chlorhexidine-containing dressing if daily chlorhexidine bathing is already established and vice-versa.
 - b. For long-term catheters (eg, hemodialysis catheters) in well-healed access sites, it is unclear whether use of a chlorhexidine dressing reduces risk of infectious complications.^{140,143,144}
 - c. For children under 2 months of age, use of chlorhexidine dressings remains unclear, particularly in very preterm or low birthweight infants.⁹⁸
3. **For nontunneled CVCs in adults and children, change transparent dressings and perform site care with a chlorhexidine-based antiseptic at least every 7 days or immediately if the**

Additional approaches for preventing CLABSI

Several additional approaches are currently available for use. Perform a CLABSI risk assessment before considering implementation of any of these approaches, taking potential adverse events and costs into consideration. Although it is reasonable to evaluate the utility of technology-based interventions when CLABSI rates are above the institutional- or unit-based threshold, this is also

an opportunity to review practices and consider behavioral changes that may be instituted to reduce CLABSI risk. These additional approaches are recommended for use in locations and/or populations within the hospital with unacceptably high CLABSI rates despite implementation of the essential CLABSI prevention strategies listed above. These measures may not be indicated if institutional goals have been consistently achieved.

1. **Use antiseptic- or antimicrobial-impregnated CVCs** (Quality of Evidence: HIGH in adult patients^{38,39,169–171} and MODERATE in pediatric patients^{172,173})
 - a. The risk of CLABSI is reduced with some currently marketed antiseptic-impregnated (eg, chlorhexidine-silver sulfadiazine) catheters and antimicrobial-impregnated (eg, minocycline-rifampin) catheters. Use such catheters under the following conditions:
 - i. Hospital units or patient populations have a CLABSI rate above institutional goals despite compliance with essential CLABSI prevention practices. Some evidence suggests that use of antimicrobial CVCs, along with other preventive technologies, may have no additional benefit in patient care units that have already established a low incidence of catheter infections.^{174,175}
 - ii. Patients have limited venous access and a history of recurrent CLABSI.
 - iii. Patients are at heightened risk of severe sequelae from a CLABSI (eg, patients with recently implanted intravascular devices such as a prosthetic heart valve or aortic graft).
 - b. Monitor patients for adverse effects such as anaphylaxis.¹⁷⁶
 - c. Many studies investigating antimicrobial-impregnated catheters were performed before infection preventive bundles were routine. Whether such catheters have an impact on CLABSI in such settings remains unknown.
2. **Use antimicrobial lock therapy for long-term CVCs** (Quality of Evidence: HIGH)^{177–184}
 - a. Antibiotic and antiseptic locks are created by filling the lumen of the catheter with a suprathreshold concentration of an antibiotic solution and leaving the solution in place until the catheter hub is re-accessed. Such an approach can reduce the risk of CLABSI. The optimal antimicrobial agent or combination of agents, their concentration, and duration of lock therapy are matters of ongoing research. Due to concerns regarding the potential for the emergence of resistance in exposed organisms, use antimicrobial locks as a preventative strategy for the following:
 - i. Patients with long-term hemodialysis catheters who have a history of recurrent CLABSI.¹⁸⁵
 - ii. Prophylaxis for patients with limited venous access and a history of recurrent CLABSI.
 - iii. Patients who are at heightened risk of severe sequelae from a CLABSI (eg, patients with recently implanted intravascular devices such as a prosthetic heart valve or aortic graft).
 - b. To minimize systemic toxicity, aspirate rather than flush the antimicrobial lock solution after the dwell time has elapsed.^{186–189} The potential of adverse effects associated with ethanol locks should be carefully considered before use.^{190,191}
3. **Use recombinant tissue plasminogen activating factor (rt-PA) once weekly after hemodialysis in patients undergoing hemodialysis through a CVC** (Quality of Evidence: HIGH)¹⁹²

4. **Utilize infusion or vascular access teams for reducing CLABSI rates** (Quality of Evidence: LOW)^{193,194}
 - a. Studies have shown that an infusion/vascular access team responsible for insertion and maintenance of *peripheral* intravenous catheters reduces the risk of bloodstream infections¹⁹⁵; however, few studies have been performed regarding the impact of intravenous therapy teams on CLABSI rates.¹⁹⁶
5. **Use antimicrobial ointments for hemodialysis catheter insertion sites** (Quality of Evidence: HIGH)^{197–201}
 - a. Apply polysporin “triple” (where available) or povidone-iodine ointment to hemodialysis catheter insertion if compatible with the catheter material.
 - b. Ingredients in ointments may interact with the chemical composition of some catheters. Thus, ensure the selected ointment will not interact with the catheter material before any such product is applied to the catheter insertion/exit site. For example, ointments containing glycol should not be applied to insertion/exit sites of polyurethane catheters.
 - c. Mupirocin ointment should not be applied to the catheter insertion site due to the risks of facilitating mupirocin resistance and the potential damage to polyurethane catheters.
6. **Use an antiseptic-containing hub/connector cap/port protector to cover connectors** (Quality of Evidence: MODERATE)^{202–208}
 - a. The utility of routinely disinfecting hub connectors and ports when using antiseptic-containing hub/connector cap/port protectors is unknown.

Approaches that should not be considered a routine part of CLABSI prevention

1. **Do not use antimicrobial prophylaxis for short-term or tunneled catheter insertion or while catheters are in situ** (Quality of Evidence: HIGH)^{209–213}
 - a. Systemic antimicrobial prophylaxis is not recommended.
2. **Do not routinely replace CVCs or arterial catheters** (Quality of Evidence: HIGH)²¹⁴
 - a. Routine catheter replacement is not recommended.

Unresolved issues

1. **Routine use of needleless connectors as a CLABSI prevention strategy before an assessment of risks, benefits, and education regarding proper use**^{215–219}
 - a. Multiple devices are currently available but the optimal design for preventing infections is unresolved. The original purpose of needleless connectors was to prevent needlestick injuries during intermittent use. No data are available regarding their use with continuous infusions. Needle-free connectors with 3-way stopcocks may increase the risk of catheter infections.²²⁰
 - i. Use of silver-coated catheter connectors may be associated with reduced intraluminal contamination in ex vivo catheters and CLABSI.^{221,222} Clinical evidence is limited regarding the risk reduction with their routine use or use of other antimicrobial catheter connectors.
2. **Surveillance of other types of catheters (eg, peripheral arterial or venous catheters)**^{11,21,22}
 - a. Peripheral arterial catheters, short-term peripheral venous catheters and midline catheters are not included in most

Table 3. CLABSI Prevention Process Measures

Assessing Compliance According to Practice	
Use of proper CVC insertion interventions: 1. Hand hygiene 2. Use of maximal sterile barrier precautions 3. Use of chlorhexidine-based cutaneous antiseptics	(Number of CVC insertions that have documented the use of all 3 interventions performed at the time of CVC insertion divided by number of all CVC insertions) $\times 100 =$ % properly performed procedures
Documentation of daily assessment regarding patient's need for continuing CVC access	(Number of CVC insertions with documentation of daily assessment divided by number of patients with CVC) $\times 100 =$ % of patients who received daily assessment for continuing need for CVC access
Assessing Compliance by Simulation	
Simulation of catheter maintenance to assess HCP competency	(Number of HCP properly simulating aseptic infusion of medications divided by number of HCP simulating the aseptic infusion of medications) $\times 100 =$ % of HCP competent in catheter maintenance
Assessing Device Utilization as a Surrogate for Patient Exposure Risk	
Standard utilization ratio (SUR)	Number of observed device days divided by number of predicted device days

surveillance systems although they are associated with risk of bloodstream infection. Future surveillance systems should consider including bloodstream infections associated with these types of catheters.

- b. If considering further infection prevention interventions due to concern for an increase in infections, hospitals may want to consider extending their surveillance programs to include all types of catheters used to gauge the size of the problem.
3. **Standard, nonantimicrobial transparent dressings and CLABSI risk**
 - a. A meta-analysis reported an association between CLABSI and transparent dressing use; however, the source studies for the meta-analysis reporting this association were of low quality.²²³
4. **The impact of using chlorhexidine-based products on bacterial resistance to chlorhexidine**
 - a. Widespread use of chlorhexidine-based products (eg, use of chlorhexidine bathing, antiseptics, and dressings) may promote reduced chlorhexidine susceptibility.²²⁴ However, testing for chlorhexidine susceptibility is not standardized. The clinical impact of reduced chlorhexidine susceptibility is unknown.
5. **Sutureless securement**
 - a. The impact of sutureless securement devices in reducing CLABSI is unknown.^{225,226}
6. **Impact of silver zeolite-impregnated umbilical catheters in preterm infants (applicable in countries where it is approved for use in children)**²²⁷
 - a. One randomized study suggests that antimicrobial-impregnated umbilical catheters appear to be safe and effective in NICU patients.²²⁸
7. **Necessity of mechanical disinfection of a catheter hub, needleless connector, and injection port before accessing the catheter when antiseptic-containing caps are being used.**
 - a. It is unknown whether the application and removal of an antiseptic-containing cap provides the same benefit to reducing risk of CLABSI as manual disinfection. Future research is needed to determine if using such a cap will obviate the need for manual disinfection before accessing a catheter.

Section 5: Performance measures

Internal reporting

These performance measures are intended to support internal hospital quality improvement efforts^{229,230} and do not necessarily address external reporting needs.

The process and outcome measures suggested here are derived from published guidelines, other relevant literature, and the opinion of the authors. Report process and outcome measures to senior hospital leadership, nursing leadership, and clinicians who care for patients at risk for CLABSI.

Process measures (Table 3)

1. **Compliance with CVC insertion guidelines as documented on an insertion checklist**
 - a. Assess compliance with the checklist in all hospital settings where CVCs are inserted (eg, ICUs, ED, OR, radiology, general patient care units) and assign HCP familiar with CVCs to this task.
 - b. Documenting compliance using the insertion checklist upholds accountability and compliance with the proper procedure steps and identifies gaps to be mitigated. The Institute for Healthcare Improvement (IHI) provides an example of a central catheter checklist.²³¹
 - c. Documentation of CVC insertion procedures in compliance with appropriate hand hygiene, use of maximal sterile barrier precautions, and use of chlorhexidine-based cutaneous antiseptics of the insertion site:
 - i. **Numerator:** Number of CVC insertions that have documented the use of all 3 interventions (hand hygiene, maximal barrier precautions, and chlorhexidine-based cutaneous antiseptic use) performed at the time of CVC insertion.
 - ii. **Denominator:** Number of all CVC insertions.
 - iii. Multiply by 100 so that the measure is expressed as a percentage.
2. **Compliance with documentation of daily assessment regarding the need for continuing CVC access.**
 - a. Measure the percentage of patients with a CVC where there is documentation of daily assessment:

Table 4. CLABSI Prevention Outcome Measures

Assessing CLABSI Rate	
Using NHSN definitions	(Number of CLABSIs in each unit assessed with NHSN definitions divided by total number of catheter days in each unit assessed using NHSN definitions) \times 1,000 = Number of CLABSIs per 1,000 catheter days
Risk Adjustment	
<i>Report comparisons based on historic data and NHSN data, if available.</i>	
By type of patient-care unit	Device standardized infection ratio (dSIR) = Observed CLABSI events divided by predicted CLABSI events based on actual device days
By the patient population level to reflect the care of the device, and interventions to reduce utilization	Population standardized infection ratio (pSIR) = Observed CLABSI events divided by predicted CLABSI events based on predicted device days

- i. **Numerator:** Number of patients with a CVC who have documentation of daily assessment.
 - ii. **Denominator:** Number of patients with a CVC.
 - iii. Multiply by 100 so that the measure is expressed as a percentage.
3. **Simulation of catheter maintenance as an alternative to address HCP competency**^{232,233}
 - i. **Numerator:** Number of HCP properly simulating the aseptic infusion of medications.
 - ii. **Denominator:** Number of HCP simulating the aseptic infusion of medications.
 - iii. Multiply by 100 so that the measure is expressed as a percentage.
4. Device utilization can be evaluated over time to assess any changes. Utilization may be compared at the hospital and unit level. It provides a surrogate for patient exposure risk.²³⁴ The standardized utilization ratio (SUR) is an NHSN measure that accounts for facility- and location-level factors that may affect device use.
 - i. SUR: Observed device days divided by predicted device days.

Outcome measures (See Table 4)

1. **CLABSI rate:** Use NHSN definitions.
 - a. **Numerator:** Number of CLABSIs in each unit assessed (using NHSN definitions).
 - b. **Denominator:** Total number of catheter days in each unit assessed (using NHSN definitions).
 - c. Multiply by 1,000 so that the measure is expressed as number of CLABSIs per 1,000 catheter days.
2. **Risk adjustment:** Stratify CLABSI rates by type of patient-care unit.^{235–237}
 - a. Report comparisons based on historic data and NHSN data, if available.¹⁶⁷
 - b. Use the NHSN device standardized infection ratio (dSIR) to evaluate hospital and unit CLABSI rates.
 - i. dSIR: Observed CLABSI events divided by predicted CLABSI events based on actual device days.
 - c. Consider measures that address device risk at the patient population level. A population SIR (pSIR)²³⁸ accounts for both device SIR and SUR, reflecting both the care of the device, and interventions to reduce utilization.
 - i. pSIR: Observed CLABSI events divided by predicted CLABSI events based on predicted device days.

External reporting

Many challenges exist in providing useful information to consumers and other stakeholders and in preventing unintended consequences of public reporting of HAIs.^{239,240} Recommendations for public reporting of HAIs have been provided by the Healthcare Infection Control Practices Advisory Committee (HICPAC),²⁴¹ the Healthcare-Associated Infection Working Group of the Joint Public Policy Committee,²⁴² and the National Quality Forum.²⁴³

State and federal requirements

1. Hospitals in states that have mandatory reporting requirements for CLABSI must collect and report the data required by the state.
2. For information on state and federal requirements, contact your state or local health department.

External quality initiatives

1. Hospitals that participate in external quality initiatives or state programs must collect and report the data required by the initiative or the program.
2. Problems with interrater reliability may affect comparisons between different institutions.

Section 6: Implementation of CLABSI prevention strategies

Prevention of CLABSI depends on integrating best practices to reduce the risk of infection and incorporating a culture to support implementation. Hospitals should address technical and socioadaptive components²⁴⁴ to CLABSI prevention, including formal training of HCP on indications, placement, and maintenance of devices, in addition to regular assessment of competencies.²⁴⁵

One example of a widely used model in the United States, known as the Four Es (ie, engage, educate, execute, and evaluate²⁴⁶), involves summarizing evidence, identifying local barriers to implementation, measuring performance, and ensuring that patients receive the infection prevention intervention²⁴⁷ by addressing knowledge, critical thinking, behavior and psychomotor skills, as well as attitudes and beliefs of all members of the healthcare team involved with the insertion and care of CVCs.^{248,249} Facilities may consider utilizing tools to promote high-reliability processes (eg, Lean Six Sigma) and to enhance teamwork (eg, Team STEPPS).

Engage

Historically, efforts have been centered around having a champion to support CLABSI reduction initiatives. Champions are often very effective in initial phases of adoption, but their efforts may not be enough for integration of processes and sustainability.²⁵⁰ It is important to engage both frontline and senior leadership champions in the process and outcome improvement plan,²⁵¹ but institutionalizing the work and garnering the support of stakeholder groups facilitates successful, long-lasting results.²⁵²

Educate

HCP, patients, and caregivers involved in care of a CVC should be trained in and competent, relative to their role, with the following:

1. Appropriate indications prior to insertion.
2. Use of full barrier precautions at the time of insertion.
3. Daily evaluation of necessity of the device.

Execute

A standardized competency assessment checklist should be used to assess and document competency of each individual performing CVC insertion and procedures related to care and maintenance (eg, dressing changes).^{253–255} In addition, education of the patient and/or family, as appropriate, is required for all CVC care procedures especially when transfer to an alternative setting (eg, home care, ambulatory setting) is planned.^{256,257}

Evaluate

Evaluation involves both process and outcome measurement.²⁵⁸ Multidisciplinary teams should set clear goals and identify the key factors to be measured. It is important for members of the healthcare team to receive feedback on their performance. Feedback should include periodic (eg, monthly, quarterly) communication (eg, e-mail messages, written reports) of process measurement data via posters, reports, or other forms of communication with graphs showing cumulative compliance with process measures.^{259–262} Differences between age groups should also be considered (eg, neonates, pediatrics, and adults).^{260,263,264} Central line data can be used to capture trends over time. The standardized utilization ratio (SUR) provides a method for the hospital's units to compare themselves to others with similar characteristics. CLABSI events are important to discuss with the different members of the team caring for the patient to have a clear understanding of gaps and ways to mitigate them in the future.

Acknowledgments. We appreciate Sarah Rolli, Bern University Hospital, for her help with document editing and formatting.

Disclaimer. The findings and conclusions in this report are those of the author and do not necessarily represent the official position of the Centers for Disease Control and Prevention.

Conflicts of interest. The following disclosures reflect what has been reported to SHEA. To provide thorough transparency, SHEA requires full disclosure of all relationships, regardless of relevancy to the topic. Such relationships as potential conflicts of interest are evaluated in a review process that includes assessment by the SHEA Conflict of Interest Committee and may include the Board of Trustees and Editor of Infection Control and Hospital Epidemiology. The assessment of disclosed relationships for possible conflicts of interest has been based on the relative weight of the financial relationship (ie, monetary amount) and the relevance of the relationship (ie, the degree to which

an association might reasonably be interpreted by an independent observer as related to the topic or recommendation of consideration).

N.B. received a Mobility grant from the Swiss National Science Foundation (grant nos. P400PM_183865 and P4P4PM_194449) and a grant from the Bangerter-Rhyner Foundation. J.M. is the recipient of a project grant on surgical site infections from the Swiss National Science Foundation (grant no. 32003B_179500, "Understanding the drivers of surgical site infection: Investigating and modeling the Swissnos surveillance data"). L.M. served as an advisor/consultant for Marvao Medical Devices. L.H. served as an advisor/consultant for B Braun Medical, BD Medical, Atrion Medical, Nexus Medical, Teleflex. M.E.R. served as an advisor/consultant for 3M, Becton Dickinson, and Cetius, and Teleflex, and received honoraria from Teleflex. All other authors report no conflicts of interest related to this article.

References

1. Marschall J, Mermel LA, Fakih M, *et al*. Strategies to prevent central line-associated bloodstream infections in acute-care hospitals: 2014 update. *Infect Control Hosp Epidemiol* 2014;35:753–771.
2. The Society for Healthcare Epidemiology of America (SHEA) Handbook for SHEA-Sponsored Guidelines and Expert Guidance Documents 2021. SHEA website. <https://shea-online.org/wp-content/uploads/2022/02/2022-Handbook-Update-Approved-Posted.pdf>. Published 2021. Accessed March 22, 2022.
3. 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.
4. 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.
5. Goudie A, Dynan L, Brady PW, Rettiganti M. Attributable cost and length of stay for central line-associated bloodstream infections. *Pediatrics* 2014;133:e1525–e1532.
6. Leistner R, Hirsemann E, Bloch A, Gastmeier P, Geffers C. Costs and prolonged length of stay of central venous catheter-associated bloodstream infections (CVC BSI): a matched prospective cohort study. *Infection* 2014;42:31–36.
7. Stevens V, Geiger K, Concannon C, Nelson RE, Brown J, Dumyati G. Inpatient costs, mortality and 30-day readmission in patients with central line-associated bloodstream infections. *Clin Microbiol Infect* 2014;20:O318–O324.
8. Ziegler MJ, Pellegrini DC, Safdar N. Attributable mortality of central line-associated bloodstream infection: systematic review and meta-analysis. *Infection* 2015;43:29–36.
9. Dube WC, Jacob JT, Zheng Z, *et al*. Comparison of Rates of central line-associated bloodstream infections in patients with 1 vs 2 central venous catheters. *JAMA Network Open* 2020;3:e200396.
10. Mermel LA. How should surveillance systems account for concurrent intravascular catheters? *JAMA Netw Open* 2020;3:e200400.
11. 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 Clin Proc* 2006;81:1159–1171.
12. European Centre for Disease Prevention and Control. *Point Prevalence Survey of Healthcare-Associated Infections and Antimicrobial use in European Acute-Care Hospitals*. Stockholm, Sweden: ECDC; 2013.
13. Marschall J, Leone C, Jones M, Nihill D, Fraser VJ, Warren DK. Catheter-associated bloodstream infections in general medical patients outside the intensive care unit: a surveillance study. *Infect Control Hosp Epidemiol* 2007;28:905–909.
14. Vital signs: central line-associated bloodstream infections—United States, 2001, 2008, and 2009. *Morb Mortal Wkly Rep* 2011;60:243–248.
15. Kallen AJ, Patel PR, O'Grady NP. Preventing catheter-related bloodstream infections outside the intensive care unit: expanding prevention to new settings. *Clin Infect Dis* 2010;51:335–341.
16. Zingg W, Sandoz L, Inan C, *et al*. Hospital-wide survey of the use of central venous catheters. *J Hosp Infect* 2011;77:304–308.

17. Rhee Y, Heung M, Chen B, Chenoweth CE. Central line-associated bloodstream infections in non-ICU inpatient wards: a 2-year analysis. *Infect Control Hosp Epidemiol* 2015;36:424–430.
18. Nguyen DB, Shugart A, Lines C, *et al*. National Healthcare Safety Network (NHSN) Dialysis Event Surveillance Report for 2014. *Clin J Am Soc Nephrol* 2017;12:1139–1146.
19. Loftus RW, Brown JR, Koff MD, *et al*. Multiple reservoirs contribute to intraoperative bacterial transmission. *Anesth Analg* 2012;114:1236–1248.
20. Zakhour R, Chaftari AM, Raad, II. Catheter-related infections in patients with haematological malignancies: novel preventive and therapeutic strategies. *Lancet Infect Dis* 2016;16:e241–e250.
21. Mermel LA. Short-term peripheral venous catheter-related bloodstream infections: a systematic review. *Clin Infect Dis* 2017;65:1757–1762.
22. O'Horo JC, Maki DG, Krupp AE, Safdar N. Arterial catheters as a source of bloodstream infection: a systematic review and meta-analysis. *Crit Care Med* 2014;42:1334–1339.
23. Almunef MA, Memish ZA, Balkhy HH, Hijazi O, Cunningham G, Francis C. Rate, risk factors, and outcomes of catheter-related bloodstream infection in a paediatric intensive care unit in Saudi Arabia. *J Hosp Infect* 2006;62:207–213.
24. Alonso-Echanove J, Edwards JR, Richards MJ, *et al*. Effect of nurse staffing and antimicrobial-impregnated central venous catheters on the risk for bloodstream infections in intensive care units. *Infect Control Hosp Epidemiol* 2003;24:916–925.
25. 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:R631–R635.
26. Rey C, Alvarez F, De-La-Rua V, *et al*. Intervention to reduce catheter-related bloodstream infections in a pediatric intensive care unit. *Intensive Care Med* 2011;37:678–685.
27. Lorente L, Jimenez A, Naranjo C, *et al*. Higher incidence of catheter-related bacteremia in jugular site with tracheostomy than in femoral site. *Infect Control Hosp Epidemiol* 2010;31:311–313.
28. Callister D, Limchaiyawat P, Eells SJ, Miller LG. Risk factors for central line-associated bloodstream infections in the era of prevention bundles. *Infect Control Hosp Epidemiol* 2015;36:214–216.
29. Milstone AM, Reich NG, Advani S, *et al*. Catheter dwell time and CLABSIs in neonates with PICCs: a multicenter cohort study. *Pediatrics* 2013;132:e1609–e1615.
30. Templeton A, Schlegel M, Fleisch F, *et al*. Multilumen central venous catheters increase risk for catheter-related bloodstream infection: prospective surveillance study. *Infection* 2008;36:322–327.
31. Pongruangporn M, Ajenjo MC, Russo AJ, *et al*. Patient- and device-specific risk factors for peripherally inserted central venous catheter-related bloodstream infections. *Infect Control Hosp Epidemiol* 2013;34:184–189.
32. Chopra V, Ratz D, Kuhn L, Lopus T, Chenoweth C, Krein S. PICC-associated bloodstream infections: prevalence, patterns, and predictors. *Am J Med* 2014;127:319–328.
33. Parienti JJ, Mongardon N, Megarbane B, *et al*. Intravascular complications of central venous catheterization by insertion site. *N Engl J Med* 2015;373:1220–1229.
34. 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.
35. Cimiotti JP, Haas J, Saiman L, Larson EL. Impact of staffing on bloodstream infections in the neonatal intensive care unit. *Arch Pediatr Adolesc Med* 2006;160:832–836.
36. Leistner R, Thurnagel S, Schwab F, Piening B, Gastmeier P, Geffers C. The impact of staffing on central venous catheter-associated bloodstream infections in preterm neonates—results of nation-wide cohort study in Germany. *Antimicrob Resist Infect Control* 2013;2:11.
37. 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.
38. 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;127:267–274.
39. 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;22:3163–171.
40. Lorente L, Lecuona M, Jimenez A, *et al*. Efficiency of chlorhexidine-silver sulfadiazine-impregnated venous catheters at subclavian sites. *Am J Infect Control* 2015;43:711–714.
41. Richards B, Chaboyer W, Bladen T, Schluter PJ. Effect of central venous catheter type on infections: a prospective clinical trial. *J Hosp Infect* 2003;54:10–17.
42. Mimoz O, Lucet JC, Kerforne T, *et al*. Skin antisepsis with chlorhexidine-alcohol versus povidone iodine-alcohol, with and without skin scrubbing, for prevention of intravascular-catheter-related infection (CLEAN): an open-label, multicentre, randomised, controlled, two-by-two factorial trial. *Lancet* 2015;386:2069–2077.
43. Yasuda H, Sanui M, Abe T, *et al*. Comparison of the efficacy of three topical antiseptic solutions for the prevention of catheter colonization: a multicenter randomized controlled study. *Crit Care* 2017;21:320.
44. 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;301:1231–1241.
45. Timsit JF, Mimoz O, Mourvillier B, *et al*. Randomized controlled trial of chlorhexidine dressing and highly adhesive dressing for preventing catheter-related infections in critically ill adults. *Am J Respir Crit Care Med* 2012;186:1272–1278.
46. National Healthcare Safety Network. Bloodstream Infection event (central line-associated bloodstream infection and non-central line-associated bloodstream infection). Centers for Disease Control and Prevention website. https://www.cdc.gov/nhsn/PDFs/pscManual/4PSC_CLABScurrent.pdf. Updated January 2022. Accessed March 22, 2022.
47. Grooth HJ, Timsit JF, Mermel L, *et al*. Validity of surrogate endpoints assessing central venous catheter-related infection: evidence from individual- and study-level analyses. *Clin Microbiol Infect* 2020;26:563–571.
48. Niedner MF. The harder you look, the more you find: catheter-associated bloodstream infection surveillance variability. *Am J Infect Control* 2010;38:585–595.
49. Tomlinson D, Mermel LA, Ethier MC, Matlow A, Gillmeister B, Sung L. Defining bloodstream infections related to central venous catheters in patients with cancer: a systematic review. *Clin Infect Dis* 2011;53:697–710.
50. Mayer J, Greene T, Howell J, Ying J, Rubin MA, Trick WE, *et al*. Agreement in classifying bloodstream infections among multiple reviewers conducting surveillance. *Clin Infect Dis* 2012;55:364–370.
51. Mermel LA, Allon M, Bouza E, *et al*. Clinical practice guidelines for the diagnosis and management of intravascular catheter-related infection: 2009 Update by the Infectious Diseases Society of America. *Clin Infect Dis* 2009;49:1–45.
52. O'Grady NP, Alexander M, Dellinger EP, *et al*. Guidelines for the prevention of intravascular catheter-related infections. *MMWR Recom Rep* 2002;51:1–29.
53. O'Grady NP, Alexander M, Burns LA, *et al*. Guidelines for the prevention of intravascular catheter-related infections. *Clin Infect Dis* 2011;52:e162–e193.
54. Masse J, Elkalioubie A, Blazejewski C, *et al*. Colonization pressure as a risk factor of ICU-acquired multidrug-resistant bacteria: a prospective observational study. *Eur J Clin Microbiol Infect Dis* 2017;36:797–805.
55. Saint S. Chapter 16. Prevention of intravascular catheter-associated infections. In: *Making Health Care Safer*. Agency for Healthcare Research and Quality website. www.ahrq.gov/clinic/ptsafety/. Published 2001. Accessed March 22, 2022.

56. Huang EY, Chen C, Abdullah F, *et al*. Strategies for the prevention of central venous catheter infections: an American Pediatric Surgical Association Outcomes and Clinical Trials Committee systematic review. *J Pediatr Surg* 2011;46:2000–2011.
57. OTILUS. Preventing central line-associated bloodstream infection: global challenges, a global perspective. The Joint Commission website. https://www.jointcommission.org/-/media/tjc/documents/resources/hai/clabsi_monographpdf.pdf. Updated May 2012. Accessed March 22, 2022.
58. Barnes S, Olmsted RN, Monsees E, *et al*. Guide to preventing central line-associated bloodstream infections. Association for Professionals in Infection Control and Epidemiology (APIC) website. https://apic.org/Resource/TinyMceFileManager/2015/APIC_CLABSI_WEB.pdf. Published 2015. Accessed March 22, 2022.
59. Gorski LA, Hadaway L, Hagle ME, *et al*. Infusion Therapy Standards of Practice, Eighth Edition. *J Infusion Nurs* 2021;44:S1–S224.
60. Bloodstream infection event (central line-associated bloodstream infection and non-central line-associated bloodstream infection). Centers for Disease Control and Prevention website. https://www.cdc.gov/nhsn/pdfs/pscmanual/4psc_clabscurrent.pdf. Published 2019. Accessed March 22, 2022.
61. Tejedor SC, Garrett G, Jacob JT, *et al*. Electronic documentation of central venous catheter days: validation is essential. *Infect Control Hosp Epidemiol* 2013;34:900–907.
62. Woeltje KF, McMullen KM, Butler AM, Goris AJ, Doherty JA. Electronic surveillance for healthcare-associated central line-associated bloodstream infections outside the intensive care unit. *Infect Control Hosp Epidemiol* 2011;32:1086–1090.
63. Pronovost PJ, Watson SR, Goeschel CA, Hyzy RC, Berenholtz SM. Sustaining reductions in central line-associated bloodstream infections in michigan intensive care units: a 10-year analysis. *Am J Med Qual* 2016;31:197–202.
64. Centers for Disease Control and Prevention. Vital signs: central line-associated bloodstream infections—United States, 2001, 2008, and 2009. *Morb Mortal Wkly Rep* 2011;60:243–248.
65. Kim JS, Holtom P, Vigen C. Reduction of catheter-related bloodstream infections through the use of a central venous line bundle: epidemiologic and economic consequences. *Am J Infect Control* 2011;39:640–646.
66. Halton KA, Cook D, Paterson DL, Safdar N, Graves N. Cost-effectiveness of a central venous catheter care bundle. *PLoS One* 2010;5:e12815.
67. Tang HJ, Lin HL, Lin YH, Leung PO, Chuang YC, Lai CC. The impact of central line insertion bundle on central line-associated bloodstream infection. *BMC Infect Dis* 2014;14:356.
68. Ista E, van der Hoven B, Kornelisse RF, *et al*. Effectiveness of insertion and maintenance bundles to prevent central line-associated bloodstream infections in critically ill patients of all ages: a systematic review and meta-analysis. *Lancet Infect Dis* 2016;16:724–734.
69. Richter JP, McAlearney AS. Targeted implementation of the Comprehensive Unit-Based Safety Program through an assessment of safety culture to minimize central line-associated bloodstream infections. *Health Care Manage Rev* 2018;43:42–49.
70. Furuya EY, Dick A, Perencevich EN, Pogorzelska M, Goldmann D, Stone PW. Central-line bundle implementation in US intensive care units and impact on bloodstream infections. *PLoS One* 2011;6:e15452.
71. Guerin K, Wagner J, Rains K, Bessesen M. Reduction in central line-associated bloodstream infections by implementation of a postinsertion care bundle. *Am J Infect Control* 2010;38:430–433.
72. Miller MR, Niedner MF, Huskins WC, *et al*. Reducing PICU central line-associated bloodstream infections: 3-year results. *Pediatrics* 2011;128:e1077–e1083.
73. O'Neil C, Ball K, Wood H, *et al*. A central-line care maintenance bundle for the prevention of central line-associated bloodstream infection in non-intensive care unit settings. *Infect Control Hosp Epidemiol* 2016;37:692–698.
74. 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.
75. 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.
76. 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;30:59–64.
77. 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;31:1959–1963.
78. 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;126:1612–1618.
79. Lobo RD, Levin AS, Oliveira MS, *et al*. Evaluation of interventions to reduce catheter-associated bloodstream infection: continuous tailored education versus one basic lecture. *Am J Infect Control* 2010;38:440–448.
80. Cherry MG, Brown JM, Neal T, Ben Shaw N. What features of educational interventions lead to competence in aseptic insertion and maintenance of CV catheters in acute care? *Med Teach* 2010;32:198–218.
81. Joint Commission Resources. *Assessing Hospital Staff Competence*. Oakbrook Terrace, IL: Joint Commission International; 2007.
82. Barsuk JH, Cohen ER, Potts S, *et al*. Dissemination of a simulation-based mastery learning intervention reduces central line-associated bloodstream infections. *BMJ Qual Saf* 2014;23:749–756.
83. Cartier V, Inan C, Zingg W, Delhumeau C, Walder B, Savoldelli GL. Simulation-based medical education training improves short and long-term competency in, and knowledge of central venous catheter insertion: a before and after intervention study. *Eur J Anaesthesiol* 2016;33:568–574.
84. Khouli H, Jahnes K, Shapiro J, *et al*. Performance of medical residents in sterile techniques during central vein catheterization: randomized trial of efficacy of simulation-based training. *Chest* 2011;139:80–87.
85. Ma IW, Brindle ME, Ronksley PE, Lorenzetti DL, Sauve RS, Ghali WA. Use of simulation-based education to improve outcomes of central venous catheterization: a systematic review and meta-analysis. *Acad Med* 2011;86:1137–1147.
86. Bleasdale SC, Trick WE, Gonzalez IM, Lyles RD, Hayden MK, Weinstein RA. Effectiveness of chlorhexidine bathing to reduce catheter-associated bloodstream infections in medical intensive care unit patients. *Arch Intern Med* 2007;167:2073–2079.
87. Milstone AM, Elward A, Song X, *et al*. Daily chlorhexidine bathing to reduce bacteraemia in critically ill children: a multicentre, cluster-randomised, crossover trial. *Lancet* 2013;381:1099–1106.
88. Climo MW, Yokoe DS, Warren DK, *et al*. Effect of daily chlorhexidine bathing on hospital-acquired infection. *N Engl J Med* 2013;368:533–542.
89. Noto MJ, Domenico HJ, Byrne DW, *et al*. Chlorhexidine bathing and healthcare-associated infections: a randomized clinical trial. *JAMA* 2015;313:369–378.
90. Afonso E, Blot K, Blot S. Prevention of hospital-acquired bloodstream infections through chlorhexidine gluconate-impregnated washcloth bathing in intensive care units: a systematic review and meta-analysis of randomised crossover trials. *Euro Surveill* 2016;21:30400.
91. Munoz-Price LS, Hota B, Stemer A, Weinstein RA. Prevention of bloodstream infections by use of daily chlorhexidine baths for patients at a long-term acute-care hospital. *Infect Control Hosp Epidemiol* 2009;30:1031–1035.
92. Medina A, Serratt T, Pelter M, Brancamp T. Decreasing central line-associated bloodstream infections in the non-ICU population. *J Nurs Care Qual* 2014;29:133–140.
93. Huang SS, Septimus E, Kleinman K, *et al*. Chlorhexidine versus routine bathing to prevent multidrug-resistant organisms and all-cause bloodstream infections in general medical and surgical units (ABATE Infection trial): a cluster-randomised trial. *Lancet* 2019;393:1205–1215.
94. Tien KL, Sheng WH, Shieh SC, *et al*. Chlorhexidine bathing to prevent central line-associated bloodstream infections in hematology units: a prospective, controlled cohort study. *Clin Infect Dis* 2020;71:556–563.
95. Zerr DM, Milstone AM, Dvorak CC, *et al*. Chlorhexidine gluconate bathing in children with cancer or those undergoing hematopoietic stem cell transplantation: a double-blinded randomized controlled trial from the Children's Oncology Group. *Cancer* 2020;127:56–66.

96. Milstone AM, Bamford P, Aucott SW, Tang N, White KR, Bearer CF. Chlorhexidine inhibits L1 cell adhesion molecule-mediated neurite outgrowth in vitro. *Pediatr Res* 2014;75:8–13.
97. Kieran EA, O'Sullivan A, Miletin J, Twomey AR, Knowles SJ, O'Donnell CPF. 2% chlorhexidine-70% isopropyl alcohol versus 10% povidone-iodine for insertion site cleaning before central-line insertion in preterm infants: a randomised trial. *Arch Dis Child Fetal Neonatal Ed* 2018;103:F101–F106.
98. Neri I, Ravaioli GM, Faldella G, Capretti MG, Arcuri S, Patrizi A. Chlorhexidine-induced chemical burns in very-low-birthweight infants. *J Pediatr* 2017;191:262–265.
99. Chandonnet CJ, Toole C, Young V, et al. Safety of biweekly chlorhexidine gluconate bathing in infants 36 to 48 weeks' postmenstrual age. *Am J Crit Care* 2019;28:451–459.
100. Kampf G. Acquired resistance to chlorhexidine—is it time to establish an 'antiseptic stewardship' initiative? *J Hosp Infect* 2016;94:213–227.
101. Wichmann D, Belmar Campos CE, et al. Efficacy of introducing a checklist to reduce central venous line associated bloodstream infections in the ICU caring for adult patients. *BMC Infect Dis* 2018;18:267.
102. Elgohari S, Wilson J, Saei A, Sheridan EA, Lamagni T. Impact of national policies on the microbial aetiology of surgical site infections in acute NHS hospitals in England: analysis of trends between 2000 and 2013 using multicentre prospective cohort data. *Epidemiol Infect* 2017;145:957–969.
103. Yilmaz G, Koksali A, Aydin K, Caylan R, Sucu N, Aksoy F. Risk factors of catheter-related bloodstream infections in parenteral nutrition catheterization. *J Parenter Enteral Nutr* 2007;31:284–287.
104. Boyce JM, Pittet D. Guideline for Hand Hygiene in Health-Care Settings. Recommendations of the Healthcare Infection Control Practices Advisory Committee and the HICPAC/SHEA/APIC/IDSA Hand Hygiene Task Force. Society for Healthcare Epidemiology of America/Association for Professionals in Infection Control/Infectious Diseases Society of America. *MMWR Recomm Rep* 2002;51:1–45.
105. Rosenthal VD, Guzman S, Safdar N. Reduction in nosocomial infection with improved hand hygiene in intensive care units of a tertiary-care hospital in Argentina. *Am J Infect Control* 2005;33:392–397.
106. Capretti MG, Sandri F, Tridapalli E, Galletti S, Petracci E, Faldella G. Impact of a standardized hand hygiene program on the incidence of nosocomial infection in very low birth weight infants. *Am J Infect Control* 2008;36:430–435.
107. van der Kooij T, Sax H, Pittet D, et al. Prevention of hospital infections by intervention and training (PROHIBIT): results of a pan-European cluster-randomized multicentre study to reduce central venous catheter-related bloodstream infections. *Intensive Care Med* 2018;44:48–60.
108. Arvaniti K, Lathyris D, Blot S, Apostolidou-Kiouti F, Koulenti D, Haidich AB. Cumulative evidence of randomized controlled and observational studies on catheter-related infection risk of central venous catheter insertion site in ICU patients: a pairwise and network meta-analysis. *Crit Care Med* 2017;45:e437–e448.
109. Parienti JJ. Catheter-related bloodstream infection in jugular versus subclavian central catheterization. *Crit Care Med* 2017;45:e734–e735.
110. Timsit JF, Bouadma L, Mimoz O, et al. Jugular versus femoral short-term catheterization and risk of infection in intensive care unit patients. Causal analysis of two randomized trials. *Am J Respir Crit Care Med* 2013;188:1232–1239.
111. Ullman AJ, Bernstein SJ, Brown E, et al. The Michigan Appropriateness Guide for Intravenous Catheters in Pediatrics: miniMAGIC. *Pediatrics* 2020;145:S269–S84.
112. Chau A, Hernandez JA, Pimpalwar S, Ashton D, Kukreja K. Equivalent success and complication rates of tunneled common femoral venous catheter placed in the interventional suite vs. at patient bedside. *Pediatr Radiol* 2018;48:889–894.
113. Gaballah M, Krishnamurthy G, Berman JJ, et al. Lower extremity vascular access in neonates and infants: a single institutional experience. *J Vasc Interv Radiol* 2015;26:1660–1668.
114. Chopra V, O'Horo JC, Rogers MA, Maki DG, Safdar N. The risk of bloodstream infection associated with peripherally inserted central catheters compared with central venous catheters in adults: a systematic review and meta-analysis. *Infect Control Hosp Epidemiol* 2013;34:908–918.
115. Ajenjo MC, Morley JC, Russo AJ, et al. Peripherally inserted central venous catheter-associated bloodstream infections in hospitalized adult patients. *Infect Control Hosp Epidemiol* 2011;32:125–130.
116. Swaminathan L, Flanders S, Horowitz J, Zhang Q, O'Malley M, Chopra V. Safety and outcomes of midline catheters vs peripherally inserted central catheters for patients with short-term indications: a multicenter study. *JAMA Intern Med* 2022;182:50–58.
117. Mushtaq A, Navalkele B, Kaur M, et al. Comparison of complications in midlines versus central venous catheters: Are midlines safer than central venous lines? *Am J Infect Control* 2018;46:788–792.
118. Berenholtz SM, Pronovost PJ, Lipsett PA, et al. Eliminating catheter-related bloodstream infections in the intensive care unit. *Crit Care Med* 2004;32:2014–2020.
119. Karakitsos D, Labropoulos N, De Groot E, et al. Real-time ultrasound-guided catheterisation of the internal jugular vein: a prospective comparison with the landmark technique in critical care patients. *Crit Care* 2006;10:R162.
120. Brass P, Hellmich M, Kolodziej L, Schick G, Smith AF. Ultrasound guidance versus anatomical landmarks for internal jugular vein catheterization. *Cochrane Database Syst Rev* 2015;1:CD006962.
121. Hind D, Calvert N, McWilliams R, et al. Ultrasonic locating devices for central venous cannulation: meta-analysis. *BMJ* 2003;327:361.
122. Buetti N, Mimoz O, Mermel L, et al. Ultrasound guidance and risk for central venous catheter-related infections in the ICU. A post hoc analysis of individual data of three multicentric randomized trials. *Clin Infect Dis* 2021;73(5):e1054–e1061.
123. 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.
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.
125. Hu KK, Lipsky BA, Veenstra DL, Saint S. Using maximal sterile barriers to prevent central venous catheter-related infection: a systematic evidence-based review. *Am J Infect Control* 2004;32:142–146.
126. Ishikawa Y, Kiyama T, Haga Y, et al. Maximal sterile barrier precautions do not reduce catheter-related bloodstream infections in general surgery units: a multi-institutional randomized controlled trial. *Ann Surg* 2010;251:620–623.
127. Burrell AR, McLaws ML, Murgu M, Calabria E, Pantle AC, Herkes R. Aseptic insertion of central venous lines to reduce bacteraemia. *Med J Aust* 2011;194:583–587.
128. Lee DH, Jung KY, Choi YH. Use of maximal sterile barrier precautions and/or antimicrobial-coated catheters to reduce the risk of central venous catheter-related bloodstream infection. *Infect Control Hosp Epidemiol* 2008;29:947–950.
129. 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.
130. Humar A, Ostromecki A, Drenfeld J, et al. Prospective randomized trial of 10% povidone-iodine versus 0.5% tincture of chlorhexidine as cutaneous antiseptic for prevention of central venous catheter infection. *Clin Infect Dis* 2000;31:1001–1007.
131. 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;136:792–801.
132. Lai NM, Lai NA, O'Riordan E, Chaiyakunapruk N, Taylor JE, Tan K. Skin antiseptics for reducing central venous catheter-related infections. *Cochrane Database Syst Rev* 2016;7:CD010140.
133. Pages J, Hazera P, Megarbane B, et al. Comparison of alcoholic chlorhexidine and povidone-iodine cutaneous antiseptics for the prevention of central venous catheter-related infection: a cohort and quasi-experimental multicenter study. *Intensive Care Med* 2016;42:1418–1426.

134. Masuyama T, Yasuda H, Sanui M, Lefor AK. Effect of skin antiseptic solutions on the incidence of catheter-related bloodstream infection: a systematic review and network meta-analysis. *J Hosp Infect* 2021;110:156–164.
135. 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.
136. Levy I, Katz J, Solter E, *et al*. Chlorhexidine-impregnated dressing for prevention of colonization of central venous catheters in infants and children: a randomized controlled study. *Pediatr Infect Dis J* 2005;24:676–679.
137. Ho KM, Litton E. Use of chlorhexidine-impregnated dressing to prevent vascular and epidural catheter colonization and infection: a meta-analysis. *J Antimicrob Chemother* 2006;58:281–287.
138. 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;301:1231–1241.
139. Ruschulte H, Franke M, Gastmeier P, *et al*. Prevention of central venous catheter related infections with chlorhexidine gluconate impregnated wound dressings: a randomized controlled trial. *Ann Hematol* 2009;88:267–272.
140. Camins BC, Richmond AM, Dyer KL, *et al*. A crossover intervention trial evaluating the efficacy of a chlorhexidine-impregnated sponge in reducing catheter-related bloodstream infections among patients undergoing hemodialysis. *Infect Control Hosp Epidemiol* 2010;31:1118–1123.
141. Ullman AJ, Cooke ML, Mitchell M, *et al*. Dressing and securement for central venous access devices (CVADs): a Cochrane systematic review. *Int J Nurs Stud* 2016;59:177–196.
142. Puig-Asensio M, Marra AR, Childs CA, Kukla ME, Perencevich EN, Schweizer ML. Effectiveness of chlorhexidine dressings to prevent catheter-related bloodstream infections. Does one size fit all? A systematic literature review and meta-analysis. *Infect Control Hosp Epidemiol* 2020;41:1388–1395.
143. Righetti M, Palmieri N, Bracchi O, *et al*. Tegaderm CHG dressing significantly improves catheter-related infection rate in hemodialysis patients. *J Vasc Access* 2016;17:417–422.
144. Apata IW, Hanfelt J, Bailey JL, Niyar VD. Chlorhexidine-impregnated transparent dressings decrease catheter-related infections in hemodialysis patients: a quality improvement project. *J Vasc Access* 2017;18:103–108.
145. 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.
146. Rasero L, Degl'Innocenti M, Mocali M. 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.
147. Timsit JF, Bouadma L, Ruckly S, *et al*. Dressing disruption is a major risk factor for catheter-related infections. *Crit Care Med* 2012;40:1707–1714.
148. Gavin NC, Webster J, Chan RJ, Rickard CM. Frequency of dressing changes for central venous access devices on catheter-related infections. *Cochrane Database Syst Rev* 2016;2:CD009213.
149. Short KL. Implementation of a central-line maintenance bundle for dislodgement and infection prevention in the NICU. *Adv Neonatal Care* 2019;19:145–150.
150. 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.
151. 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.
152. Casey AL, Worthington T, Lambert PA, Quinn D, Faroqui MH, Elliott TS. A randomized, prospective clinical trial to assess the potential infection risk associated with the PosiFlow needleless connector. *J Hosp Infect* 2003;54:288–293.
153. Munoz-Price LS, Dezfulian C, Wyckoff M, *et al*. Effectiveness of stepwise interventions targeted to decrease central catheter-associated bloodstream infections. *Crit Care Med* 2012;40:1464–1469.
154. Soothill JS, Bravery K, Ho A, Macqueen S, Collins J, Lock P. A fall in bloodstream infections followed a change to 2% chlorhexidine in 70% isopropanol for catheter connection antiseptics: a pediatric single center before/after study on a hemopoietic stem cell transplant ward. *Am J Infect Control* 2009;37:626–630.
155. Hong H, Morrow DF, Sandora TJ, Priebe GP. Disinfection of needleless connectors with chlorhexidine-alcohol provides long-lasting residual disinfectant activity. *Am J Infect Control* 2013;41(8):e77–e79.
156. Rupp ME, Yu S, Huerta T, *et al*. Adequate disinfection of a split-septum needleless intravascular connector with a 5-second alcohol scrub. *Infect Control Hosp Epidemiol* 2012;33:661–665.
157. Simmons S, Bryson C, Porter S. “Scrub the hub”: cleaning duration and reduction in bacterial load on central venous catheters. *Crit Care Nurs Q* 2011;34:31–35.
158. Hankins R, Majorant OD, Rupp ME, *et al*. Microbial colonization of intravascular catheter connectors in hospitalized patients. *Am J Infect Control* 2019;47:1489–1492.
159. van der Kooi T, Sax H, Pittet D, *et al*. Prevention of hospital infections by intervention and training (PROHIBIT): results of a pan-European cluster-randomized multicentre study to reduce central venous catheter-related bloodstream infections. *Intensive Care Med* 2018;44:48–60.
160. Rotz S, Sopirala MM. Assessment beyond central-line bundle: audits for line necessity in infected central lines in a surgical intensive care unit. *Am J Infect Control* 2012;40:88–89.
161. Cload B, Day AG, Ilan R. Evaluation of unnecessary central venous catheters in critically ill patients: a prospective observational study. *Can J Anaesth* 2010;57:830–835.
162. Seguin P, Laviolle B, Isslame S, Coue A, Malledant Y. Effectiveness of simple daily sensitization of physicians to the duration of central venous and urinary tract catheterization. *Intensive Care Med* 2010;36:1202–1206.
163. Faruqi A, Medefindt J, Dutta G, Philip SA, Tompkins D, Carey J. Effect of a multidisciplinary intervention on central-line utilization in an acute-care hospital. *Am J Infect Control* 2012;40:e211–e115.
164. Rickard CM, Marsh NM, Larsen EN, *et al*. Effect of infusion set replacement intervals on catheter-related bloodstream infections (RSVP): a randomised, controlled, equivalence (central venous access device)-non-inferiority (peripheral arterial catheter) trial. *Lancet* 2021;397:1447–1458.
165. Gastmeier P, Geffers C, Brandt C, *et al*. Effectiveness of a nationwide nosocomial infection surveillance system for reducing nosocomial infections. *J Hosp Infect* 2006;64:16–22.
166. Zingg W, Sax H, Inan C, *et al*. Hospital-wide surveillance of catheter-related bloodstream infection: from the expected to the unexpected. *J Hosp Infect* 2009;73:41–46.
167. Sunkesula VCK, Kundrapu S, Knighton S, Cadnum JL, Donskey CJ. A Randomized trial to determine the impact of an educational patient hand-hygiene intervention on contamination of hospitalized patient's hands with healthcare-associated pathogens. *Infect Control Hosp Epidemiol* 2017;38:595–597.
168. Lin MY, Hota B, Khan YM, *et al*. Quality of traditional surveillance for public reporting of nosocomial bloodstream infection rates. *JAMA* 2010;304:2035–2041.
169. Wang H, Tong H, Liu H, *et al*. Effectiveness of antimicrobial-coated central venous catheters for preventing catheter-related bloodstream infections with the implementation of bundles: a systematic review and network meta-analysis. *Ann Intensive Care* 2018;8:71.
170. Chong HY, Lai NM, Apisarntharak A, Chaiyakunapruk N. Comparative efficacy of antimicrobial central venous catheters in reducing catheter-related bloodstream infections in adults: abridged cochrane systematic review and network meta-analysis. *Clin Infect Dis* 2017;64:S131–S140.
171. Novikov A, Lam MY, Mermel LA, Casey AL, Elliott TS, Nightingale P. Impact of catheter antimicrobial coating on species-specific risk of

- catheter colonization: a meta-analysis. *Antimicrob Resist Infect Control* 2012;1:40.
172. Gilbert RE, Mok Q, Dwan K, *et al*. Impregnated central venous catheters for prevention of bloodstream infection in children (the CATCH trial): a randomised controlled trial. *Lancet* 2016;387:1732–1742.
 173. Lai L, Yue X. Efficacy of antimicrobial-impregnated catheters for prevention of bloodstream infections in pediatric patients: a meta-analysis. *Front Pediatr* 2021;9:632308.
 174. Cherry-Bukowicz JR, Denchev K, Dickinson S, *et al*. Prevention of catheter-related blood stream infection: back to basics? *Surg Infect (Larchmt)* 2011;12:27–32.
 175. Ullman AJ, Paterson RS, Schults JA, *et al*. Do antimicrobial and antithrombotic peripherally inserted central catheter (PICC) materials prevent catheter complications? An analysis of 42,562 hospitalized medical patients. *Infect Control Hosp Epidemiol* 2021. doi: [10.1017/ice.2021.141](https://doi.org/10.1017/ice.2021.141).
 176. Guleri A, Kumar A, Morgan RJ, Hartley M, Roberts DH. Anaphylaxis to chlorhexidine-coated central venous catheters: a case series and review of the literature. *Surg Infect (Larchmt)* 2012;13:171–174.
 177. 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.
 178. 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.
 179. Safdar N, Maki DG. Use of vancomycin-containing lock or flush solutions for prevention of bloodstream infection associated with central venous access devices: a meta-analysis of prospective, randomized trials. *Clin Infect Dis* 2006;43:474–484.
 180. Labriola L, Crott R, Jadoul M. Preventing haemodialysis catheter-related bacteraemia with an antimicrobial lock solution: a meta-analysis of prospective randomized trials. *Nephrol Dialysis Transpl* 2008;23:1666–1672.
 181. Snaterse M, Ruger W, Scholte Op Reimer WJ, Lucas C. Antibiotic-based catheter lock solutions for prevention of catheter-related bloodstream infection: a systematic review of randomised controlled trials. *J Hosp Infect* 2010;75:1–11.
 182. Oliveira C, Nasr A, Brindle M, Wales PW. Ethanol locks to prevent catheter-related bloodstream infections in parenteral nutrition: a meta-analysis. *Pediatrics* 2012;129:318–329.
 183. Zacharioudakis IM, Zervou FN, Arvanitis M, Ziakas PD, Mermel LA, Mylonakis E. Antimicrobial lock solutions as a method to prevent central line-associated bloodstream infections: a meta-analysis of randomized controlled trials. *Clin Infect Dis* 2014;59:1741–1749.
 184. Sheng KX, Zhang P, Li JW, *et al*. Comparative efficacy and safety of lock solutions for the prevention of catheter-related complications including infectious and bleeding events in adult haemodialysis patients: a systematic review and network meta-analysis. *Clin Microbiol Infect* 2020;26:545–552.
 185. Arechabala MC, Catoni MI, Claro JC, *et al*. Antimicrobial lock solutions for preventing catheter-related infections in haemodialysis. *Cochrane Database Syst Rev* 2018;4:CD010597.
 186. Opilla MT, Kirby DF, Edmond MB. Use of ethanol lock therapy to reduce the incidence of catheter-related bloodstream infections in home parenteral nutrition patients. *J Parenter Enteral Nutr* 2007;31:302–305.
 187. Slobbe L, Doorduyn JK, Lugtenburg PJ, *et al*. Prevention of catheter-related bacteremia with a daily ethanol lock in patients with tunneled catheters: a randomized, placebo-controlled trial. *PLoS One* 2010;5:e10840.
 188. Cober MP, Kovacevich DS, Teitelbaum DH. Ethanol-lock therapy for the prevention of central venous access device infections in pediatric patients with intestinal failure. *J Parenter Enteral Nutr* 2011;35:67–73.
 189. Heng AE, Abdelkader MH, Diaconita M, *et al*. Impact of short term use of interdialytic 60% ethanol lock solution on tunneled silicone catheter dysfunction. *Clin Nephrol* 2011;75:534–541.
 190. Mermel LA, Alang N. Adverse effects associated with ethanol catheter lock solutions: a systematic review. *J Antimicrob Chemother* 2014;69:2611–2619.
 191. Wolf J, Connell TG, Allison KJ, *et al*. Treatment and secondary prophylaxis with ethanol lock therapy for central line-associated bloodstream infection in paediatric cancer: a randomised, double-blind, controlled trial. *Lancet Infect Dis* 2018;18:854–863.
 192. Hemmelgarn BR, Moist LM, Lok CE, *et al*. Prevention of dialysis catheter malfunction with recombinant tissue plasminogen activator. *N Engl J Med* 2011;364:303–312.
 193. Miller JM, Goetz AM, Squier C, Muder RR. Reduction in nosocomial intravenous device-related bacteremias after institution of an intravenous therapy team. *J Intravenous Nurs* 1996;19:103–106.
 194. Taylor T, Massaro A, Williams L, *et al*. Effect of a dedicated percutaneously inserted central catheter team on neonatal catheter-related bloodstream infection. *Adv Neonatal Care* 2011;11:122–128.
 195. 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.
 196. Carr PJ, Higgins NS, Cooke ML, Mihala G, Rickard CM. Vascular access specialist teams for device insertion and prevention of failure. *Cochrane Database Syst Rev* 2018;3:CD011429.
 197. 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.
 198. 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 Dialysis Transpl* 1998;13:1870–1871.
 199. Lok CE, Stanley KE, Hux JE, Richardson R, Tobe SW, Conly J. Hemodialysis infection prevention with polysporin ointment. *J Am Soc Nephrol* 2003;14:169–179.
 200. Battistella M, Bhola C, Lok CE. Long-term follow-up of the Hemodialysis Infection Prevention with Polysporin Ointment (HIPPO) study: a quality improvement report. *Am J Kidney Dis* 2011;57:432–441.
 201. James MT, Conley J, Tonelli M, Manns BJ, MacRae J, Hemmelgarn BR. Meta-analysis: antibiotics for prophylaxis against hemodialysis catheter-related infections. *Ann Intern Med* 2008;148:596–605.
 202. Oto J, Imanaka H, Konno M, Nakataki E, Nishimura M. A prospective clinical trial on prevention of catheter contamination using the hub protection cap for needleless injection device. *Am J Infect Control* 2011;39:309–313.
 203. Sweet MA, Cumpston A, Briggs F, Craig M, Hamadani M. Impact of alcohol-impregnated port protectors and needleless neutral pressure connectors on central line-associated bloodstream infections and contamination of blood cultures in an inpatient oncology unit. *Am J Infect Control* 2012;40:931–934.
 204. Wright MO, Tropp J, Schora DM, *et al*. Continuous passive disinfection of catheter hubs prevents contamination and bloodstream infection. *Am J Infect Control* 2013;41:33–38.
 205. Loftus RW, Brindeiro BS, Kispert DP, *et al*. Reduction in intraoperative bacterial contamination of peripheral intravenous tubing through the use of a passive catheter care system. *Anesth Analg* 2012;115:1315–1323.
 206. Hymes JL, Mooney A, Van Zandt C, Lynch L, Ziebol R, Killion D. Dialysis catheter-related bloodstream infections: a cluster-randomized trial of the ClearGuard HD antimicrobial barrier cap. *Am J Kidney Dis* 2017;69:220–227.
 207. Brunelli SM, Van Wyck DB, Njord L, Ziebol RJ, Lynch LE, Killion DP. Cluster-randomized trial of devices to prevent catheter-related bloodstream infection. *J Am Soc Nephrol* 2018;29:1336–1343.
 208. Flynn JM, Larsen EN, Keogh S, Ullman AJ, Rickard CM. Methods for microbial needleless connector decontamination: a systematic review and meta-analysis. *Am J Infect Control* 2019;47:956–962.
 209. 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.

210. 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.
211. Sandoe JA, Kumar B, Stoddart B, *et al*. Effect of extended perioperative antibiotic prophylaxis on intravascular catheter colonization and infection in cardiothoracic surgery patients. *J Antimicrob Chemother* 2003;52: 877–879.
212. Karanlik H, Kurul S, Saip P, *et al*. The role of antibiotic prophylaxis in totally implantable venous access device placement: results of a single-center prospective randomized trial. *Am J Surg* 2011;202:10–15.
213. van de Wetering MD, van Woensel JB, Lawrie TA. Prophylactic antibiotics for preventing gram-positive infections associated with long-term central venous catheters in oncology patients. *Cochrane Database Syst Rev* 2013;CD003295.
214. 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.
215. Maragakis LL, Bradley KL, Song X, *et al*. Increased catheter-related bloodstream infection rates after the introduction of a new mechanical valve intravenous access port. *Infect Control Hosp Epidemiol* 2006; 27:67–70.
216. Field K, McFarlane C, Cheng AC, *et al*. Incidence of catheter-related bloodstream infection among patients with a needleless, mechanical valve-based intravenous connector in an Australian hematology-oncology unit. *Infect Control Hosp Epidemiol* 2007;28:610–613.
217. Salgado CD, Chinnes L, Paczesny TH, Cantey JR. Increased rate of catheter-related bloodstream infection associated with use of a needleless mechanical valve device at a long-term acute-care hospital. *Infect Control Hosp Epidemiol* 2007;28:684–688.
218. Rupp ME, Sholtz LA, Jourdan DR, *et al*. Outbreak of bloodstream infection temporally associated with the use of an intravascular needleless valve. *Clin Infect Dis* 2007;44:1408–1414.
219. Jarvis WR, Murphy C, Hall KK, *et al*. Health care-associated bloodstream infections associated with negative- or positive-pressure or displacement mechanical valve needleless connectors. *Clin Infect Dis* 2009;49: 1821–1827.
220. Rosenthal VD. Impact of needle-free connectors compared with 3-way stopcocks on catheter-related bloodstream infection rates: a meta-analysis. *Am J Infect Control* 2020;48:281–284.
221. Casey AL, Karpanen TJ, Nightingale P, Cook M, Elliott TS. Microbiological comparison of a silver-coated and a non-coated needleless intravascular connector in clinical use. *J Hosp Infect* 2012;80:299–303.
222. Jacob JT, Chernetsky Tejedor S, Dent Reyes M, *et al*. Comparison of a silver-coated needleless connector and a standard needleless connector for the prevention of central line-associated bloodstream infections. *Infect Control Hosp Epidemiol* 2015;36:294–301.
223. Webster J, Gillies D, O'Riordan E, Sherriff KL, Rickard CM. Gauze and tape and transparent polyurethane dressings for central venous catheters. *Cochrane Database Syst Rev* 2011;CD003827.
224. Batra R, Cooper BS, Whiteley C, Patel AK, Wyncoll D, Edgeworth JD. Efficacy and limitation of a chlorhexidine-based decolonization strategy in preventing transmission of methicillin-resistant *Staphylococcus aureus* in an intensive care unit. *Clin Infect Dis* 2010;50:210–217.
225. Rickard CM, Edwards M, Spooner AJ, *et al*. A 4-arm randomized controlled pilot trial of innovative solutions for jugular central venous access device securement in 221 cardiac surgical patients. *J Crit Care* 2016; 36:35–42.
226. Karpanen TJ, Casey AL, Whitehouse T, *et al*. A clinical evaluation of two central venous catheter stabilization systems. *Ann Intensive Care* 2019; 9:49.
227. Bertini G, Elia S, Ceciarini F, Dani C. Reduction of catheter-related bloodstream infections in preterm infants by the use of catheters with the AgION antimicrobial system. *Early Hum Dev* 2013;89:21–25.
228. Bertini G, Elia S, Ceciarini F, Dani C. Reduction of catheter-related bloodstream infections in preterm infants by the use of catheters with the AgION antimicrobial system. *Early Hum Dev* 2013;89:21–25.
229. Bizzarro MJ, Sabo B, Noonan M, *et al*. A quality improvement initiative to reduce central line-associated bloodstream infections in a neonatal intensive care unit. *Infect Control Hosp Epidemiol* 2010;31:241–248.
230. Sawyer M, Weeks K, Goeschel CA, *et al*. Using evidence, rigorous measurement, and collaboration to eliminate central catheter-associated bloodstream infections. *Crit Care Med* 2010;38:S292–S298.
231. Central-line insertion checklist: Virginia Mason Medical Center example. Institute for Healthcare Improvement website. <http://www.ihl.org/resources/Pages/Tools/CentralLineInsertionChecklist.aspx>. Accessed March 22, 2022.
232. Fakhri MG, Jones K, Rey JE, *et al*. Sustained improvements in peripheral venous catheter care in non-intensive care units: a quasi-experimental controlled study of education and feedback. *Infect Control Hosp Epidemiol* 2012;33:449–455.
233. Fakhri MG, Jones K, Rey JE, *et al*. Peripheral venous catheter care in the emergency department: education and feedback lead to marked improvements. *Am J Infect Control* 2013;41:531–536.
234. Fakhri MG, Gould CV, Trautner BW, *et al*. Beyond infection: device utilization ratio as a performance measure for urinary catheter harm. *Infect Control Hosp Epidemiol* 2016;37:327–333.
235. Widmer AF, Nettlesman M, Flint K, Wenzel RP. The clinical impact of culturing central venous catheters. A prospective study. *Arch Intern Med* 1992;152:1299–1302.
236. 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.
237. 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.
238. Fakhri MG, Huang RH, Bufalino A, *et al*. The case for a population standardized infection ratio (SIR): a metric that marries the device SIR to the standardized utilization ratio (SUR). *Infect Control Hosp Epidemiol* 2019;40:979–982.
239. Wong ES, Rupp ME, Mermel L, *et al*. Public disclosure of healthcare-associated infections: the role of the Society for Healthcare Epidemiology of America. *Infect Control Hosp Epidemiol* 2005;26:210–212.
240. Aswani MS, Reagan J, Jin L, Pronovost PJ, Goeschel C. Variation in public reporting of central line-associated bloodstream infections by state. *Am J Med Qual* 2011;26:387–395.
241. Talbot TR, Bratzler DW, Carrico RM, *et al*. Public reporting of healthcare-associated surveillance data: recommendations from the healthcare infection control practices advisory committee. *Ann Intern Med* 2013;159: 631–635.
242. Evans ME, Kralovic SM, Simbartl LA, Jain R, Roselle GA. Eight years of decreased methicillin-resistant *Staphylococcus aureus* healthcare-associated infections associated with a Veterans' Affairs prevention initiative. *Am J Infect Control* 2017;45:13–16.
243. Hamill ME, Reed CR, Fogel SL, *et al*. Contact isolation precautions in trauma patients: an analysis of infectious complications. *Surg Infect (Larchmt)* 2017;18:273–281.
244. Chopra V, Flanders SA, Saint S, *et al*. The Michigan Appropriateness Guide for Intravenous Catheters (MAGIC): results from a multispecialty panel using the RAND/UCLA appropriateness method. *Ann Intern Med* 2015;163:S1–S40.
245. Fakhri MG, Heavens M, Ratcliffe CJ, Hendrich A. First step to reducing infection risk as a system: evaluation of infection prevention processes for 71 hospitals. *Am J Infect Control* 2013;41:950–954.
246. Owings A, Graves J, Johnson S, Gilliam C, Gipson M, Hakim H. Leadership line care rounds: application of the engage, educate, execute, and evaluate improvement model for the prevention of central line-associated bloodstream infections in children with cancer. *Am J Infect Control* 2018;46:229–231.
247. Pronovost PJ, Berenholtz SM, Needham DM. Translating evidence into practice: a model for large scale knowledge translation. *BMJ* 2008;337: a1714.
248. Safdar N, Abad C. Educational interventions for prevention of healthcare-associated infection: a systematic review. *Crit Care Med* 2008;36: 933–940.

249. Smith JS, Kirksey KM, Becker H, Brown A. Autonomy and self-efficacy as influencing factors in nurses' behavioral intention to disinfect needleless intravenous systems. *J Infus Nurs* 2011;34:193–200.
250. Hendy J, Barlow J. The role of the organizational champion in achieving health system change. *Social Sci Med* 2012;74:348–355.
251. Weaver SJ, Lubomksi LH, Wilson RF, Pfoh ER, Martinez KA, Dy SM. Promoting a culture of safety as a patient safety strategy: a systematic review. *Ann Intern Med* 2013;158:369–374.
252. Fakhri MG, Krein SL, Edson B, Watson SR, Battles JB, Saint S. Engaging healthcare workers to prevent catheter-associated urinary tract infection and avert patient harm. *Am J Infect Control* 2014;42:S223–S229.
253. Wathen C, Kshetry VR, Krishnaney A, et al. The association between operating room personnel and turnover with surgical site infection in more than 12,00 neurosurgical cases. *Neurosurgery* 2016;79:889–894.
254. Huang GC, Newman LR, Schwartzstein RM, et al. Procedural competence in internal medicine residents: validity of a central venous catheter insertion assessment instrument. *Acad Med* 2009;84:1127–1134.
255. Evans LV, Dodge KL. Simulation and patient safety: evaluative checklists for central venous catheter insertion. *Qual Saf Health Care* 2010;19 suppl 3:i42–i46.
256. Segreti J, Garcia-Houchins S, Gorski L, et al. Consensus conference on prevention of central line-associated bloodstream infections: 2009. *J Infus Nurs* 2011;34:126–133.
257. Nailon RE, Rupp ME, Lyden E. A day in the life of a CVAD. *J Infusion Nurs* 2019;42:125–131.
258. Wheeler DS, Giaccone MJ, Hutchinson N, et al. A hospital-wide quality-improvement collaborative to reduce catheter-associated bloodstream infections. *Pediatrics* 2011;128:e995–e1004.
259. Marra AR, Cal RG, Duraio MS, et al. Impact of a program to prevent central line-associated bloodstream infection in the zero tolerance era. *Am J Infect Control* 2010;38:434–439.
260. Powers RJ, Wirtschafter DW. Decreasing central line-associated bloodstream infection in neonatal intensive care. *Clin Perinatol* 2010;37:247–272.
261. Berhe M, Edmond MB, Bearman G. Measurement and feedback of infection control process measures in the intensive care unit: Impact on compliance. *Am J Infect Control* 2006;34:537–539.
262. Assanasen S, Edmond M, Bearman G. Impact of 2 different levels of performance feedback on compliance with infection control process measures in 2 intensive care units. *Am J Infect Control* 2008;36:407–413.
263. Miller MR, Griswold M, Harris JM, 2nd, et al. Decreasing PICU catheter-associated bloodstream infections: NACHRI's quality transformation efforts. *Pediatrics* 2010;125:206–213.
264. Stevens TP, Schulman J. Evidence-based approach to preventing central line-associated bloodstream infection in the NICU. *Acta Paediatr Suppl* 2012;101:11–16.
265. Guyatt GH, Oxman AD, Vist GE, et al. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. *BMJ* 2008;336:924–926.
266. Canadian Task Force on Preventive Health Care website. <http://canadiantaskforce.ca/methods/grade/>. Accessed December 31, 2021.