

Practice Guidelines for Central Venous Access 2020

*An Updated Report by the American Society of Anesthesiologists Task Force on Central Venous Access**

Practice guidelines are systematically developed recommendations that assist the practitioner and patient in making decisions about health care. These recommendations may be adopted, modified, or rejected according to clinical needs and constraints and are not intended to replace local institutional policies. In addition, practice guidelines developed by the American Society of Anesthesiologists (ASA) are not intended as standards or absolute requirements, and their use cannot guarantee any specific outcome. Practice guidelines are subject to revision as warranted by the evolution of medical knowledge, technology, and practice. They provide basic recommendations that are supported by a synthesis and analysis of the current literature, expert and practitioner opinion, open forum commentary, and clinical feasibility data.

This document updates the “Practice Guidelines for Central Venous Access: A Report by the American Society of Anesthesiologists Task Force on Central Venous Access,” adopted by the ASA in 2011 and published in 2012.¹

Methodology

Definition of Central Venous Access

For these guidelines, central venous access is defined as placement of a catheter such that the catheter is inserted into a venous great vessel. The venous great vessels include the superior vena cava, inferior vena cava, brachiocephalic veins, internal jugular veins, subclavian veins, iliac veins, and

common femoral veins.[†] Excluded are catheters that terminate in a systemic artery.

Purposes of the Guidelines

The purposes of these guidelines are to (1) provide guidance regarding placement and management of central venous catheters; (2) reduce infectious, mechanical, thrombotic, and other adverse outcomes associated with central venous catheterization; and (3) improve management of arterial trauma or injury arising from central venous catheterization.

Focus

These guidelines apply to patients undergoing elective central venous access procedures performed by anesthesiologists or healthcare professionals under the direction/supervision of anesthesiologists. The guidelines do not address (1) clinical indications for placement of central venous catheters; (2) emergency placement of central venous catheters; (3) patients with peripherally inserted central catheters; (4) placement and residence of a pulmonary artery catheter; (5) insertion of tunneled central lines (e.g., permacaths, portacaths, Hickman, Quinton); (6) methods of detection or treatment of infectious complications associated with central venous catheterization; (7) removal of central venous catheters[‡]; (8) diagnosis and management of central venous catheter-associated trauma or injury (e.g., pneumothorax or air embolism), with the exception of carotid arterial injury;

Supplemental Digital Content is available for this article. Direct URL citations appear in the printed text and are available in both the HTML and PDF versions of this article. Links to the digital files are provided in the HTML text of this article on the Journal's Web site (www.anesthesiology.org).

Received from the American Society of Anesthesiologists, Schaumburg, Illinois. Submitted for publication March 15, 2019. Accepted for publication May 16, 2019. Supported by the American Society of Anesthesiologists and developed under the direction of the Committee on Standards and Practice Parameters, Jeffrey L. Apfelbaum, M.D. (Chair). Approved by the American Society of Anesthesiologists House of Delegates on October 23, 2019. These guidelines have been endorsed by the Society of Cardiovascular Anesthesiologists and the Society for Pediatric Anesthesia.

A complete bibliography used to develop this updated Advisory, arranged alphabetically by author, is available as Supplemental Digital Content 1, <http://links.lww.com/ALN/C6>.

*Updated by the American Society of Anesthesiologists Task Force on Central Venous Access: Jeffrey L. Apfelbaum, M.D. (Committee Chair), Chicago, Illinois; Stephen M. Rupp, M.D. (Co-Chair), Seattle, Washington; Avery Tung, M.D. (Co-Chair), Wilmette, Illinois; Richard T. Connis, Ph.D. (Chief Methodologist), Woodinville, Washington; Karen B. Domino, M.D., M.P.H., Seattle, Washington; Mark D. Grant, M.D., Ph.D. (Senior Methodologist), Schaumburg, Illinois; and Jonathan B. Mark, M.D., Durham, North Carolina.

†This description of the venous great vessels is consistent with the venous subset for central lines defined by the National Healthcare Safety Network.

‡Although catheter removal is not addressed by these guidelines (and is not typically performed by anesthesiologists), the risk of venous air embolism upon removal is a serious concern. Suggestions for minimizing such risk are those directed at raising central venous pressure during and immediately after catheter removal and following a defined nursing protocol. These suggestions include, but are not limited to, positioning the patient in the Trendelenburg position, using the Valsalva maneuver, applying direct pressure to the puncture site, using air-occlusive dressings, and monitoring the patient for a reasonable period of time after catheter removal.

Copyright © 2019, the American Society of Anesthesiologists, Inc. All Rights Reserved. Anesthesiology 2020; 132:8–43. DOI: 10.1097/ALN.0000000000002864

(9) management of periinsertion coagulopathy; and (10) competency assessment for central line insertion.

Application

These guidelines are intended for use by anesthesiologists and individuals under the supervision of an anesthesiologist. They also may serve as a resource for other physicians (*e.g.*, surgeons, radiologists), nurses, or healthcare providers who manage patients with central venous catheters.

Task Force Members

The original guidelines were developed by an ASA appointed task force of 12 members, consisting of anesthesiologists in private and academic practices from various geographic areas of the United States and two methodologists from the ASA Committee on Standards and Practice Parameters. In 2017, the ASA Committee on Standards and Practice Parameters requested that these guidelines be updated. This update is a revision developed by an ASA-appointed task force of seven members, including five anesthesiologists and two methodologists. Conflict-of-interest documentation regarding current or potential financial and other interests pertinent to the practice guideline were disclosed by all task force members and managed.

Process and Evaluation of Evidence

These updated guidelines were developed by means of a five-step process. First, consensus was reached on the criteria for evidence. Second, original published articles from peer-reviewed journals relevant to the perioperative management of central venous catheters were evaluated and added to literature included in the original guidelines. Third, consultants who had expertise or interest in central venous catheterization and who practiced or worked in various settings (*e.g.*, private and academic practice) were asked to participate in opinion surveys addressing the appropriateness, completeness, and feasibility of implementation of the draft recommendations and to review and comment on a draft of the guidelines. Fourth, additional opinions were solicited from random samples of active ASA members. Fifth, all available information was used to build consensus to finalize the guidelines. A summary of recommendations can be found in appendix 1.

Preparation of these updated guidelines followed a rigorous methodological process. Evidence was obtained from two principal sources: scientific evidence and opinion-based evidence. Detailed descriptions of the ASA process and methodology used in these guidelines may be found in other related publications.^{2–5} Appendix 1 contains a footnote indicating where information may be found on the evidence model, literature search process, literature findings, and survey results for these guidelines.

Within the text of these guidelines, literature classifications are reported for each intervention using the following:

Category A level 1, meta-analysis of randomized controlled trials (RCTs); Category A level 2, multiple RCTs; Category A level 3, a single RCT; Category B level 1, nonrandomized studies with group comparisons; Category B level 2, nonrandomized studies with associative findings; Category B level 3, nonrandomized studies with descriptive findings; and Category B level 4, case series or case reports. Statistically significant outcomes ($P < 0.01$) are designated as either beneficial (B) or harmful (H) for the patient; statistically nonsignificant findings are designated as equivocal (E). Survey findings from task force-appointed expert consultants and a random sample of the ASA membership are fully reported in the text of these guidelines. Survey responses for each recommendation are reported using a 5-point scale based on median values from strongly agree to strongly disagree.

Guidelines

Resource Preparation

Resource preparation topics include (1) assessing the physical environment where central venous catheterization is planned to determine the feasibility of using aseptic techniques; (2) availability of a standardized equipment set; (3) use of a checklist or protocol for central venous catheter placement and maintenance; and (4) use of an assistant for central venous catheterization.

Literature Findings. The literature is insufficient to evaluate the effect of the physical environment for aseptic catheter insertion, availability of a standardized equipment set, or the use of an assistant on outcomes associated with central venous catheterization. An observational study reports that implementation of a trauma intensive care unit multidisciplinary checklist is associated with reduced catheter-related infection rates (*Category B2-B evidence*).⁶ Observational studies report that central line-associated or catheter-related bloodstream infection rates are reduced when intensive care unit-wide bundled protocols are implemented^{7–36} (*Category B2-B evidence*); evidence from fewer observational studies is equivocal^{37–55} (*Category B2-E evidence*); other observational studies^{56–71} do not report levels of statistical significance or lacked sufficient data to calculate them. These studies do not permit assessing the effect of any single component of a checklist or bundled protocol on infection rates.

Survey Findings. The consultants and ASA members strongly agree with the recommendation to perform central venous catheterization in an environment that permits use of aseptic techniques and to ensure that a standardized equipment set is available for central venous access. The consultants strongly agree and ASA members agree with the recommendation to use a checklist or protocol for placement and maintenance of central venous catheters. The consultants and ASA members agree with the recommendation to use an assistant during placement of a central venous catheter.

Recommendations for Resource Preparation

- Perform central venous catheterization in an environment that permits use of aseptic techniques
- Ensure that a standardized equipment set is available for central venous access[§]
- Use a checklist or protocol for placement and maintenance of central venous catheters^{||}
- Use an assistant during placement of a central venous catheter[#]

Prevention of Infectious Complications

Interventions intended to prevent infectious complications associated with central venous access include, but are not limited to, (1) intravenous antibiotic prophylaxis; (2) aseptic preparation of practitioner, staff, and patients; (3) selection of antiseptic solution; (4) selection of catheters containing antimicrobial agents; (5) selection of catheter insertion site; (6) catheter fixation method; (7) insertion site dressings; (8) catheter maintenance procedures; and (9) aseptic techniques using an existing central venous catheter for injection or aspiration.

Intravenous Antibiotic Prophylaxis

Literature Findings. The literature is insufficient to evaluate outcomes associated with the routine use of intravenous prophylactic antibiotics.

Survey Findings. The consultants strongly agree and ASA members agree with the recommendation to not routinely administer intravenous antibiotic prophylaxis.

Aseptic Preparation of Practitioner, Staff, and Patients

Literature Findings. An RCT comparing maximal barrier precautions (*i.e.*, mask, cap, gloves, gown, large full-body drape) with a control group (*i.e.*, gloves and small drape) reports equivocal findings for reduced colonization and catheter-related septicemia (*Category A3-E evidence*).⁷² A majority of observational studies reporting or with calculable levels of statistical significance report that “bundles” of aseptic protocols (*e.g.*, combinations of hand washing, sterile full-body drapes, sterile gloves, caps, and masks) reduce the frequency of central line-associated or catheter-related bloodstream infections (*Category B2-B evidence*).^{7–36} These studies do not permit assessing the effect of any single component of a bundled protocol on infection rates.

Survey Findings. The consultants and ASA members strongly agree with the recommendation to use aseptic techniques (*e.g.*, hand washing) and maximal barrier precautions (*e.g.*, sterile gowns, sterile gloves, caps, masks covering both mouth and nose, and full-body patient drapes) in preparation for the placement of central venous catheters.

[§]Refer to appendix 2 for an example of a list of standardized equipment for adult patients.

^{||}Refer to appendix 3 for an example of a checklist or protocol.

[#]Refer to appendix 4 for an example of a list of duties performed by an assistant.

Selection of Antiseptic Solution

Literature Findings. One RCT comparing chlorhexidine (2% aqueous solution without alcohol) with povidone-iodine (10% without alcohol) for skin preparation reports equivocal findings for catheter colonization and catheter-related bacteremia (*Category A3-E evidence*).⁷³ An RCT comparing chlorhexidine (2% with 70% isopropyl alcohol) with povidone-iodine (5% with 69% ethanol) with or without scrubbing finds lower rates of catheter colonization for chlorhexidine (*Category A3-B evidence*) and equivocal evidence for decreased catheter-related bloodstream infection (*Category A3-E evidence*).⁷⁴ A third RCT compared two chlorhexidine concentrations (0.5% or 1.0% in 79% ethanol) with povidone-iodine (10% without alcohol), reporting equivocal evidence for colonization (*Category A3-E evidence*) and catheter-related bloodstream infection (*Category A3-E evidence*).⁷⁵ A quasiexperimental study (secondary analysis of an RCT) reports a lower rate of catheter-related bloodstream infection with chlorhexidine (2% with 70% alcohol) than povidone-iodine (5% with 69% alcohol) (*Category B1-B evidence*).⁷⁶ The literature is insufficient to evaluate the safety of antiseptic solutions containing chlorhexidine in neonates, infants and children.”

Comparative studies are insufficient to evaluate the efficacy of chlorhexidine and alcohol compared with chlorhexidine without alcohol for skin preparation during central venous catheterization. An RCT of 5% povidone-iodine with 70% alcohol compared with 10% povidone-iodine alone indicates that catheter tip colonization is reduced with alcohol containing solutions (*Category A3-B evidence*); equivocal findings are reported for catheter-related bloodstream infection and clinical signs of infection (*Category A3-E evidence*).⁷⁷

Survey Findings. The consultants and ASA members strongly agree with the recommendation to use a chlorhexidine-containing solution for skin preparation in adults, infants, and children. For neonates, the consultants and ASA members agree with the recommendation to determine the use of chlorhexidine-containing solutions for skin preparation based on clinical judgment and institutional protocol. If there is a contraindication to chlorhexidine, the consultants strongly agree and ASA members agree with the recommendation that povidone-iodine or alcohol may be used. The consultants and ASA members agree with the recommendation to use skin preparation solutions containing alcohol unless contraindicated.

Catheters Containing Antimicrobial Agents

Literature Findings. Meta-analyses of RCTs comparing antibiotic-coated with uncoated catheters indicates that antibiotic-coated catheters are associated with reduced catheter colonization^{78–85} and catheter-related bloodstream infection (*Category A1-B evidence*).^{80,81,83,85,86} Meta-analyses of RCTs comparing silver or silver-platinum-carbon-impregnated

*See 2017 Food and Drug Administration warning on chlorhexidine allergy.

catheters with uncoated catheters yield equivocal findings for catheter colonization (*Category A1-E evidence*)^{87–97} but a decreased risk of catheter-related bloodstream infection (*Category A1-B evidence*).^{87–94,96–99} Meta-analyses of RCTs indicate that catheters coated with chlorhexidine and silver sulfadiazine reduce catheter colonization compared with uncoated catheters (*Category A1-B evidence*)^{83,95,100–118} but are equivocal for catheter-related bloodstream infection (*Category A1-E evidence*).^{83,100–102,104–110,112–117,119,120} Cases of anaphylactic shock are reported after placement of a catheter coated with chlorhexidine and silver sulfadiazine (*Category B4-H evidence*).^{121–129}

Survey Findings. The consultants and ASA members agree with the recommendation to use catheters coated with antibiotics or a combination of chlorhexidine and silver sulfadiazine based on infectious risk and anticipated duration of catheter use for selected patients. The consultants strongly agree and ASA members agree with the recommendation to not use catheters containing antimicrobial agents as a substitute for additional infection precautions.

Selection of Catheter Insertion Site

Literature Findings. RCTs comparing subclavian and femoral insertion sites report higher rates of catheter colonization at the femoral site (*Category A2-H evidence*); findings for catheter-related sepsis or catheter-related bloodstream infection are equivocal (*Category A2-E evidence*).^{130,131} An RCT finds a higher rate of catheter colonization for internal jugular compared with subclavian insertion (*Category A3-H evidence*) and for femoral compared with internal jugular insertion (*Category A3-H evidence*); evidence is equivocal for catheter-related bloodstream infection for either comparison (*Category A3-E evidence*).¹³¹ A nonrandomized comparative study of burn patients reports that catheter colonization and catheter-related bloodstream infection occur more frequently with an insertion site closer to the burn location (*Category B1-H evidence*).¹³²

Survey Findings. The consultants and ASA members strongly agree with the recommendations to (1) determine catheter insertion site selection based on clinical need; (2) select an insertion site that is not contaminated or potentially contaminated (e.g., burned or infected skin, inguinal area, adjacent to tracheostomy, or open surgical wound); and (3) select an upper body insertion site when possible to minimize the risk of infection in adults.

Catheter Fixation

Literature Findings. The literature is insufficient to evaluate whether catheter fixation with sutures, staples, or tape is associated with a higher risk for catheter-related infections.

Survey Findings. The consultants strongly agree and ASA members agree with the recommendation to determine the use of sutures, staples, or tape for catheter fixation on a local or institutional basis. The consultants and ASA members both strongly agree with the recommendation to minimize the number of needle punctures of the skin.

Insertion Site Dressings

Literature Findings. The literature is insufficient to evaluate the efficacy of transparent bioocclusive dressings to reduce the risk of infection. Pooled estimates from RCTs are consistent with lower rates of catheter colonization with chlorhexidine sponge dressings compared with standard polyurethane (*Category A1-B evidence*)^{90,133–138} but equivocal for catheter-related bloodstream infection (*Category A1-E evidence*).^{90,133–140} An RCT reports a higher frequency of severe localized contact dermatitis in neonates with chlorhexidine-impregnated dressings compared with povidone-iodine-impregnated dressings (*Category A3-H evidence*)¹³³; findings concerning dermatitis from RCTs in adults are equivocal (*Category A2-E evidence*).^{90,134,136,137,141}

Survey Findings. The consultants and ASA members both strongly agree with the recommendations to use transparent bioocclusive dressings to protect the site of central venous catheter insertion from infection. The consultants and ASA members both agree with the recommendation that dressings containing chlorhexidine may be used in adults, infants, and children unless contraindicated. For neonates, the consultants and ASA members agree with the recommendation to determine the use of transparent or sponge dressings containing chlorhexidine based on clinical judgment and institutional protocol. If a chlorhexidine-containing dressing is used, the consultants and ASA members both strongly agree with the recommendation to observe the site daily for signs of irritation, allergy or, necrosis.

Catheter Maintenance

Catheter maintenance consists of (1) determining the optimal duration of catheterization, (2) conducting catheter site inspections, (3) periodically changing catheters, and (4) changing catheters using a guidewire instead of selecting a new insertion site.

Literature Findings. Nonrandomized comparative studies indicate that longer catheterization is associated with higher catheter colonization rates, infection, and sepsis (*Category B1-H evidence*).^{21,142–145} The literature is insufficient to evaluate whether time intervals between catheter site inspections are associated with the risk for catheter-related infection. RCTs report equivocal findings for catheter tip colonization when catheters are changed at 3-day *versus* 7-day intervals (*Category A2-E evidence*).^{146,147} RCTs report equivocal findings for catheter tip colonization when guidewires are used to change catheters compared with new insertion sites (*Category A2-E evidence*).^{148–150}

Survey Findings. The consultants and ASA members strongly agree with the following recommendations: (1) determine the duration of catheterization based on clinical need; (2) assess the clinical need for keeping the catheter in place on a daily basis; (3) remove catheters promptly when no longer deemed clinically necessary; (4) inspect the catheter insertion site daily for signs of infection; (5) change or

remove the catheter when catheter insertion site infection is suspected; and (6) when a catheter-related infection is suspected, replace the catheter using a new insertion site rather than changing the catheter over a guidewire.

Aseptic Techniques Using an Existing Central Venous Catheter for Injection or Aspiration

Aseptic techniques using an existing central venous catheter for injection or aspiration consist of (1) wiping the port with an appropriate antiseptic, (2) capping stopcocks or access ports, and (3) use of needleless catheter connectors or access ports.

Literature Findings. The literature is insufficient to evaluate whether cleaning ports or capping stopcocks when using an existing central venous catheter for injection or aspiration decreases the risk of catheter-related infections. RCTs comparing needleless connectors with standard caps indicate lower rates of microbial contamination of stopcock entry ports with needleless connectors (*Category A2-B evidence*),^{151–153} but findings for catheter-related bloodstream infection are equivocal (*Category A2-E evidence*).^{151,154}

Survey Findings. The consultants and ASA members strongly agree with the recommendations to wipe catheter access ports with an appropriate antiseptic (e.g., alcohol) before each access when using an existing central venous catheter for injection or aspiration and to cap central venous catheter stopcocks or access ports when not in use. The consultants and ASA members agree that needleless catheter access ports may be used on a case-by-case basis

Recommendations for Prevention of Infectious Complications

Intravenous Antibiotic Prophylaxis

- Do not routinely administer intravenous antibiotic prophylaxis

Aseptic Preparation

- In preparation for the placement of central venous catheters, use aseptic techniques (e.g., hand washing) and maximal barrier precautions (e.g., sterile gowns, sterile gloves, caps, masks covering both mouth and nose, full-body patient drapes, and eye protection)

Selection of Antiseptic Solution

- Use a chlorhexidine-containing solution for skin preparation in adults, infants, and children
 - For neonates, determine the use of chlorhexidine-containing solutions for skin preparation based on clinical judgment and institutional protocol
- If there is a contraindication to chlorhexidine, povidone-iodine or alcohol may be used
- Unless contraindicated, use skin preparation solutions containing alcohol

Catheters Containing Antimicrobial Agents

- For selected patients, use catheters coated with antibiotics, a combination of chlorhexidine and silver sulfadiazine, or silver-platinum-carbon-impregnated catheters based on risk of infection and anticipated duration of catheter use
 - Do not use catheters containing antimicrobial agents as a substitute for additional infection precautions

Selection of Catheter Insertion Site

- Determine catheter insertion site selection based on clinical need
- Select an insertion site that is not contaminated or potentially contaminated (e.g., burned or infected skin, inguinal area, adjacent to tracheostomy or open surgical wound)
- In adults, select an upper body insertion site when possible to minimize the risk of infection

Catheter Fixation

- Determine the use of sutures, staples, or tape for catheter fixation on a local or institutional basis
- Minimize the number of needle punctures of the skin

Insertion Site Dressings

- Use transparent bioocclusive dressings to protect the site of central venous catheter insertion from infection
- Unless contraindicated, dressings containing chlorhexidine may be used in adults, infants, and children
- For neonates, determine the use of transparent or sponge dressings containing chlorhexidine based on clinical judgment and institutional protocol
- If a chlorhexidine-containing dressing is used, observe the site daily for signs of irritation, allergy, or necrosis

Catheter Maintenance

- Determine the duration of catheterization based on clinical need
- Assess the clinical need for keeping the catheter in place on a daily basis
- Remove catheters promptly when no longer deemed clinically necessary
- Inspect the catheter insertion site daily for signs of infection
- Change or remove the catheter when catheter insertion site infection is suspected
- When a catheter-related infection is suspected, a new insertion site may be used for catheter replacement rather than changing the catheter over a guidewire

Aseptic Techniques Using an Existing Central Venous Catheter for Injection or Aspiration

- Clean catheter access ports with an appropriate antiseptic (e.g., alcohol) before each access when using an existing central venous catheter for injection or aspiration

- Cap central venous catheter stopcocks or access ports when not in use
- Needleless catheter access ports may be used on a case-by-case basis

Prevention of Mechanical Trauma or Injury

Interventions intended to prevent mechanical trauma or injury associated with central venous access include but are not limited to (1) selection of catheter insertion site; (2) positioning the patient for needle insertion and catheter placement; (3) needle insertion, wire placement, and catheter placement; (4) guidance for needle, guidewire, and catheter placement, and (5) verification of needle, wire, and catheter placement.

Selection of Catheter Insertion Site

Literature Findings. RCTs comparing subclavian and femoral insertion sites report that the femoral site has a higher risk of thrombotic complications in adult patients (*Category A2-H evidence*)^{130,131}; one RCT¹³¹ concludes that thrombosis risk is higher with internal jugular than subclavian catheters (*Category A3-H evidence*), whereas for femoral *versus* internal jugular catheters, findings are equivocal (*Category A3-E evidence*). RCTs report equivocal findings for successful venipuncture when the internal jugular site is compared with the subclavian site (*Category A2-E evidence*).^{131,155,156} Equivocal findings are also reported for the femoral *versus* subclavian site (*Category A2-E evidence*)^{130,131} and the femoral *versus* internal jugular site (*Category A3-E evidence*).¹³¹ RCTs examining mechanical complications (primarily arterial injury, hematoma, and pneumothorax) report equivocal findings for the femoral *versus* subclavian site (*Category A2-E evidence*)^{130,131} as well as the internal jugular *versus* subclavian or femoral sites (*Category A3-E evidence*).¹³¹

Survey Findings. The consultants and ASA members strongly agree with the recommendation to determine catheter insertion site selection based on clinical need and practitioner judgment, experience, and skill. The consultants agree and ASA members strongly agree with the recommendations to select an upper body insertion site to minimize the risk of thrombotic complications relative to the femoral site.

Positioning the Patient for Needle Insertion and Catheter Placement

Literature Findings. Although observational studies report that Trendelenburg positioning (*i.e.*, head down from supine) increases the right internal jugular vein diameter or cross-sectional area in adult volunteers (*Category B2-B evidence*),^{157–161} findings are equivocal for studies enrolling adult patients (*Category B2-E evidence*).^{158,162–164} Observational studies comparing the Trendelenburg position and supine position in pediatric patients report increased right internal jugular vein diameter or cross-sectional area (*Category B2-B evidence*),^{165–167} and one observational study of newborns reported similar findings (*Category B2-B evidence*).¹⁶⁸ The

literature is insufficient to evaluate whether Trendelenburg positioning improves insertion success rates or decreases the risk of mechanical complications.

Survey Findings. The consultants and ASA members strongly agree with the recommendation to perform central venous access in the neck or chest with the patient in the Trendelenburg position when clinically appropriate and feasible.

Needle Insertion, Wire Placement, and Catheter Placement

Needle insertion, wire placement, and catheter placement includes (1) selection of catheter size and type; (2) use of a wire-through-thin-wall needle technique (*i.e.*, Seldinger technique) *versus* a catheter-over-the-needle-then-wire-through-the-catheter technique (*i.e.*, modified Seldinger technique); (3) limiting the number of insertion attempts; and (4) introducing two catheters in the same central vein.

Literature Findings. Case reports describe severe injury (*e.g.*, hemorrhage, hematoma, pseudoaneurysm, arteriovenous fistula, arterial dissection, neurologic injury including stroke, and severe or lethal airway obstruction) when unintentional arterial cannulation occurs with large-bore catheters (*Category B4-H evidence*).^{169–178}

An RCT comparing a thin-wall needle technique *versus* a catheter-over-the-needle for right internal jugular vein insertion in adults reports equivocal findings for first-attempt success rates and frequency of complications (*Category A3-E evidence*)¹⁷⁹; for right-sided subclavian insertion in adults an RCT reports first-attempt success more likely and fewer complications with a thin-wall needle technique (*Category A3-B evidence*).¹⁸⁰ One RCT reports equivocal findings for first-attempt success rates and frequency of complications when comparing a thin-wall needle with catheter-over-the-needle technique for internal jugular vein insertion (preferentially right) in neonates (*Category A3-E evidence*).¹⁸¹ Observational studies report a greater frequency of complications occurring with increasing number of insertion attempts (*Category B3-H evidence*).^{182–184} One nonrandomized comparative study reports a higher frequency of dysrhythmia when two central venous catheters are placed in the same vein (right internal jugular) compared with placement of one catheter in the vein (*Category B1-H evidence*); differences in carotid artery punctures or hematomas were not noted (*Category B1-E evidence*).¹⁸⁵

Survey Findings. The consultants and ASA members strongly agree with the recommendation to select catheter size (*i.e.*, outside diameter) and type based on the clinical situation and skill/experience of the operator. The consultants and ASA members agree with the recommendations to (1) select the smallest size catheter appropriate for the clinical situation; (2) select a thin-wall needle (*i.e.*, Seldinger) technique *versus* a catheter-over-the-needle (*i.e.*, modified Seldinger) technique for the subclavian approach; (3) select a thin-wall needle or catheter-over-the-needle technique for the jugular or femoral approach based on the clinical situation

and the skill/experience of the operator; and (4) base the decision to use a thin-wall needle technique or a catheter-over-the-needle technique at least in part on the method used to confirm that the wire resides in the vein before a dilator or large-bore catheter is threaded. The consultants agree and ASA members strongly agree that the number of insertion attempts should be based on clinical judgment and that the decision to place two catheters in a single vein should be made on a case-by-case basis.

Guidance for Needle, Wire, and Catheter Placement

Guidance for needle, wire, and catheter placement includes (1) real-time or dynamic ultrasound for vessel localization and guiding the needle to its intended venous location and (2) static ultrasound imaging for the purpose of prepuncture vessel localization.

Literature Findings. Meta-analyses of RCTs comparing real-time ultrasound-guided venipuncture of the internal jugular with an anatomical landmark approach report higher first insertion attempt success rates,^{186–197} higher overall success rates,^{186–188,190–201,203,205} lower rates of arterial puncture,^{186–188,190–201,203,205} and fewer insertion attempts (*Category A1-B evidence*).^{188,190,191,194–197,199,200,203–205} RCTs also indicate reduced access time or times to cannulation with ultrasound compared with a landmark approach (*Category A2-B evidence*).^{188,191,194–196,199,200,202–205}

For the subclavian vein, RCTs report fewer insertion attempts with real-time ultrasound-guided venipuncture (*Category A2-B evidence*).^{206,207} and higher overall success rates (*Category A2-B evidence*).^{206–208} When compared with a landmark approach, findings are equivocal for arterial puncture^{207,208} and hematoma (*Category A2-E evidence*).^{207,208} For the femoral vein, an RCT reports a higher first-attempt success rate and fewer needle passes with real-time ultrasound-guided venipuncture compared with the landmark approach in pediatric patients (*Category A3-B evidence*).²⁰⁹

Meta-analyses of RCTs comparing static ultrasound with a landmark approach yields equivocal evidence for improved overall success for internal jugular insertion (*Category A1-E evidence*).^{190,202,210–212} overall success irrespective of insertion site (*Category A1-E evidence*).^{182,190,202,210–212} or impact on arterial puncture rates (*Category A1-E evidence*).^{190,202,210–212} RCTs comparing static ultrasound with a landmark approach for locating the internal jugular vein report a higher first insertion attempt success rate with static ultrasound (*Category A3-B evidence*).^{190,212} The literature is equivocal regarding overall success for subclavian vein access (*Category A3-E evidence*).¹⁸² or femoral vein access when comparing static ultrasound to the landmark approach (*Category A3-E evidence*).²⁰²

Survey Findings. The consultants and ASA members strongly agree with the recommendation to use real-time ultrasound guidance for vessel localization and venipuncture when the internal jugular vein is selected for cannulation. The consultants and ASA members agree that when

feasible, real-time ultrasound may be used when the subclavian or femoral vein is selected. The consultants strongly agree and ASA members agree with the recommendation to use static ultrasound imaging before prepping and draping for prepuncture identification of anatomy to determine vessel localization and patency when the internal jugular vein is selected for cannulation. The consultants and ASA members agree that static ultrasound may also be used when the subclavian or femoral vein is selected.

Verification of Needle, Wire, and Catheter Placement

Verification of needle, wire, and catheter placement includes (1) confirming that the catheter or thin-wall needle resides in the vein, (2) confirming venous residence of the wire, and (3) confirming residence of the catheter in the venous system and final catheter tip position.^{††}

Literature Findings. A retrospective observational study reports that manometry can detect arterial punctures not identified by blood flow and color (*Category B3-B evidence*).²¹³ The literature is insufficient to address ultrasound, pressure-waveform analysis, blood gas analysis, blood color, or the absence of pulsatile flow as effective methods of confirming catheter or thin-wall needle venous access.

Two observational studies indicate that ultrasound can confirm venous placement of the wire before dilation or final catheterization (*Category B3-B evidence*).^{214,215} Observational studies also demonstrate that transthoracic ultrasound can confirm residence of the guidewire in the venous system (*Category B3-B evidence*).^{216–219} One observational study indicates that transesophageal echocardiography can be used to identify guidewire position (*Category B3-B evidence*).²²⁰ and case reports document similar findings (*Category B4-B evidence*).^{221,222}

Observational studies indicate that transthoracic ultrasound can confirm correct catheter tip position (*Category B2-B evidence*).^{216,217,223–240,††§§} Observational studies also indicate that fluoroscopy^{241,242} and chest radiography^{243,244} can identify the position of the catheter (*Category B2-B evidence*). RCTs comparing continuous electrocardiographic guidance for catheter placement with no electrocardiography indicate that continuous electrocardiography is more effective in identifying proper catheter tip placement (*Category A2-B evidence*).^{245–247} Case reports document unrecognized retained guidewires resulting in complications including embolization and fragmentation,²⁴⁸ infection,²⁴⁹ arrhythmia,²⁵⁰ cardiac perforation,²⁴⁸ stroke,²⁵¹ and migration through soft-tissue (*Category B-4H evidence*).²⁵²

††Verification methods for needle, wire, or catheter placement may include any one or more of the following: ultrasound, manometry, pressure-waveform analysis, venous blood gas, fluoroscopy, continuous electrocardiography, transesophageal echocardiography, and chest radiography.

‡‡Studies also report high specificities of transthoracic ultrasound for excluding the presence of a pneumothorax.^{216,218,219,227–229,232,233,236,238,240}

§§Chest radiography was used as a reference standard for these studies.

Survey Findings. The consultants and ASA members strongly agree with the recommendation to confirm venous access after insertion of a catheter that went over the needle or a thin-wall needle and with the recommendation to not rely on blood color or absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein. The consultants strongly agree and ASA members agree with the recommendation to confirm venous residence of the wire after the wire is threaded when using the thin-wall needle technique. The consultants are equivocal and ASA members agree that when using the catheter-over-the-

needle technique, confirmation that the wire resides in the vein may not be needed (1) if the catheter enters the vein easily and manometry or pressure-waveform measurement provides unambiguous confirmation of venous location of the catheter and (2) if the wire passes through the catheter and enters the vein without difficulty. The consultants and ASA members strongly agree with the recommendation to confirm venous residence of the wire after the wire is threaded if there is any uncertainty that the catheter or wire resides in the vein, and insertion of a dilator or large-bore catheter may then proceed. The consultants and ASA

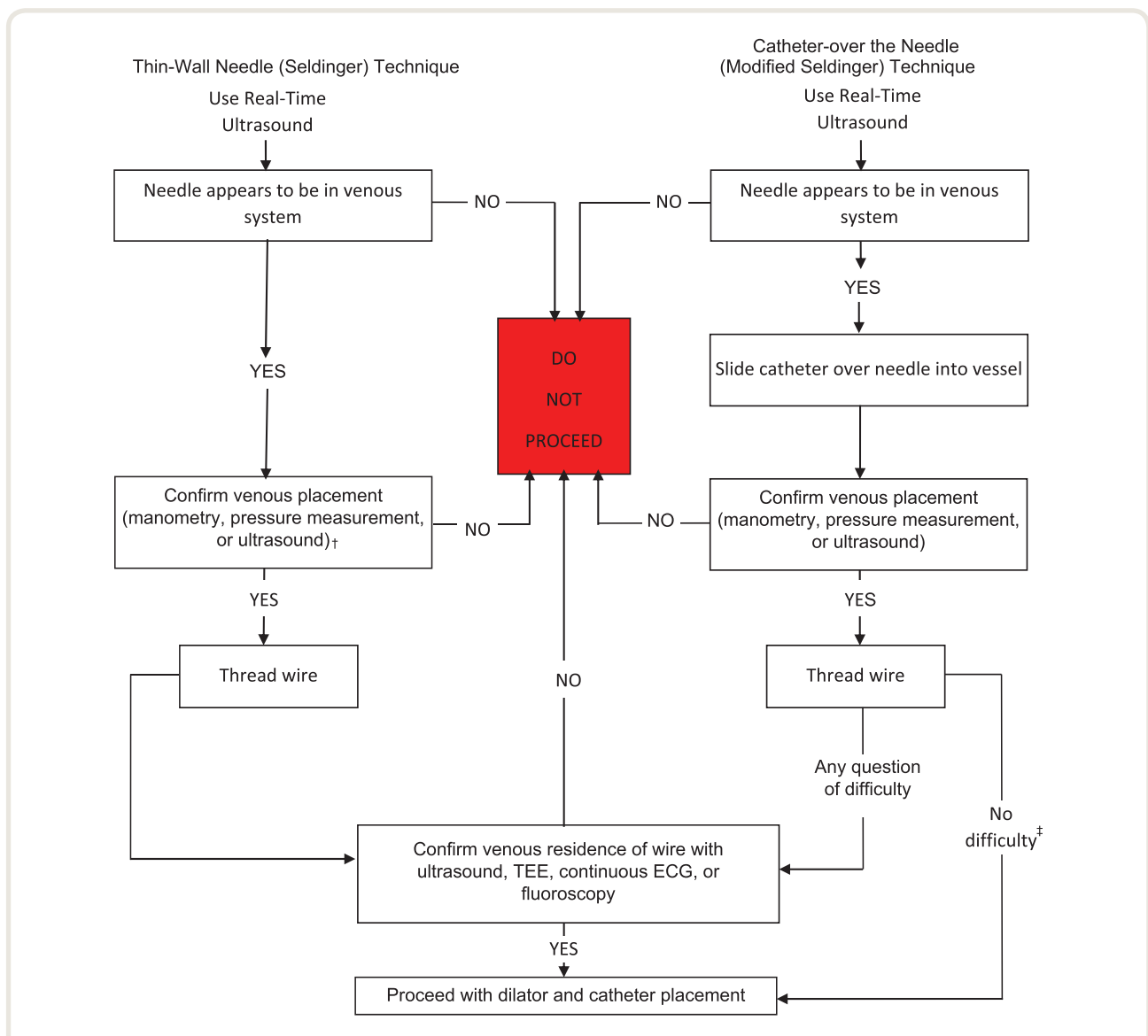


Fig. 1. Algorithm for central venous insertion and verification. This algorithm compares the thin-wall needle (*i.e.*, Seldinger) technique *versus* the catheter-over the needle (*i.e.*, modified Seldinger) technique in critical safety steps to prevent unintentional arterial placement of a dilator or large-bore catheter. The variation between the two techniques reflects mitigation steps for the risk that the thin-wall needle in the Seldinger technique could move out of the vein and into the wall of an artery between the manometry step and the threading of the wire step. ECG, electrocardiography; TEE, transesophageal echocardiography. †For neonates, infants, and children, confirmation of venous placement may take place after the wire is threaded. ‡Consider confirming venous residence of the wire.

members strongly agree with the following recommendations: (1) after final catheterization and before use, confirm residence of the catheter in the venous system as soon as clinically appropriate; (2) confirm the final position of the catheter tip as soon as clinically appropriate; (3) for central venous catheters placed in the operating room, perform a chest radiograph no later than the early postoperative period to confirm the position of the catheter tip; (4) verify that the wire has not been retained in the vascular system at the end of the procedure by confirming the presence of the removed wire in the procedural field; and (5) if the complete guidewire is not found in the procedural field, order chest radiography to determine whether the guidewire has been retained in the patient's vascular system.

Recommendations for Prevention of Mechanical Trauma or Injury

Catheter Insertion Site Selection

- Determine catheter insertion site selection based on clinical need and practitioner judgment, experience, and skill
- Select an upper body insertion site when possible to minimize the risk of thrombotic complications relative to the femoral site

Positioning the Patient for Needle Insertion and Catheter Placement

- Perform central venous access in the neck or chest with the patient in the Trendelenburg position when clinically appropriate and feasible

Needle Insertion, Wire Placement, and Catheter Placement

- Select catheter size (*i.e.*, outside diameter) and type based on the clinical situation and skill/experience of the operator
- Select the smallest size catheter appropriate for the clinical situation
- For the subclavian approach select a thin-wall needle (*i.e.*, Seldinger) technique *versus* a catheter-over-the-needle (*i.e.*, modified Seldinger) technique
- For the jugular or femoral approach, select a thin-wall needle or catheter-over-the-needle technique based on the clinical situation and the skill/experience of the operator
- For accessing the vein before threading a dilator or large-bore catheter, base the decision to use a thin-wall needle technique or a catheter-over-the-needle technique at least in part on the method used to confirm that the wire resides in the vein (fig. 1)^{¶¶}
- The number of insertion attempts should be based on clinical judgment
- The decision to place two catheters in a single vein should be made on a case-by-case basis

¶¶ The catheter over-the-needle technique may provide more stable venous access if manometry is used for venous confirmation.

Guidance of Needle, Wire, and Catheter Placement

- Use real-time ultrasound guidance for vessel localization and venipuncture when the internal jugular vein is selected for cannulation (see fig. 1)^{##}
 - When feasible, real-time ultrasound may be used when the subclavian or femoral vein is selected
- Use static ultrasound imaging before prepping and draping for prepuncture identification of anatomy to determine vessel localization and patency when the internal jugular vein is selected for cannulation
 - Static ultrasound may also be used when the subclavian or femoral vein is selected

Verification of Needle, Wire, and Catheter Placement

- After insertion of a catheter that went over the needle or a thin-wall needle, confirm venous access^{***†††}
 - Do not rely on blood color or absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein
- When using the thin-wall needle technique, confirm venous residence of the wire after the wire is threaded
 - When using the catheter-over-the-needle technique, confirmation that the wire resides in the vein may not be needed (1) when the catheter enters the vein easily and manometry or pressure-waveform measurement provides unambiguous confirmation of venous location of the catheter and (2) when the wire passes through the catheter and enters the vein without difficulty
 - If there is any uncertainty that the catheter or wire resides in the vein, confirm venous residence of the wire after the wire is threaded; insertion of a dilator or large-bore catheter may then proceed^{‡‡}
- After final catheterization and before use, confirm residence of the catheter in the venous system as soon as clinically appropriate^{§§§}

This approach may not be feasible in emergency circumstances or in the presence of other clinical constraints.

*** For neonates, infants, and children, confirmation of venous placement may take place after the wire is threaded.

††† Methods for confirming that the catheter or thin-wall needle resides in the vein include, but are not limited to, ultrasound, manometry, or pressure-waveform analysis measurement.

‡‡ Methods for confirming that the wire resides in the vein include, but are not limited to, ultrasound (identification of the wire in the vein) or transesophageal echocardiography (identification of the wire in the superior vena cava or right atrium), continuous electrocardiography (identification of narrow-complex ectopy), or fluoroscopy.

§§§ Methods for confirming that the catheter is still in the venous system after catheterization and before use include manometry, pressure-waveform measurement, or contrast-enhanced ultrasound.

- Confirm the final position of the catheter tip as soon as clinically appropriate^{||||}
 - For central venous catheters placed in the operating room, perform a chest radiograph no later than the early postoperative period to confirm the position of the catheter tip
- Verify that the wire has not been retained in the vascular system at the end of the procedure by confirming the presence of the removed wire in the procedural field
 - If the complete guidewire is not found in the procedural field, order chest radiography to determine whether the guidewire has been retained in the patient's vascular system

Management of Arterial Trauma or Injury Arising from Central Venous Catheterization

Literature Findings. Case reports of adult patients with arterial puncture by a large-bore catheter/vessel dilator during attempted central venous catheterization indicate severe complications (e.g., cerebral infarction, arteriovenous fistula, hemothorax) after immediate catheter removal (*Category B4-H evidence*)^{172,176,253}; complications are uncommonly reported for adult patients whose catheters were left in place before surgical consultation and repair (*Category B4-E evidence*).^{172,176,254}

Survey Findings. The consultants and ASA members strongly agree that when unintended cannulation of an arterial vessel with a dilator or large-bore catheter occurs, leave the dilator or catheter in place and immediately consult a general surgeon, a vascular surgeon, or an interventional radiologist regarding surgical or nonsurgical catheter removal for adults. The consultants and ASA members strongly agree that for neonates, infants, and children, determine on a case-by-case basis whether to leave the catheter in place and obtain consultation or to remove the catheter nonsurgically. The consultants strongly agree and ASA members agree with the recommendation that after the injury has been evaluated and a treatment plan has been executed, confer with the surgeon regarding relative risks and benefits of proceeding with the elective surgery *versus* deferring surgery to allow for a period of patient observation.

Recommendations for Management of Arterial Trauma or Injury Arising from Central Venous Access

- When unintended cannulation of an arterial vessel with a dilator or large-bore catheter occurs, leave the dilator or catheter in place and immediately consult a general surgeon, a vascular surgeon, or an interventional radiologist regarding surgical or nonsurgical catheter removal for adults

|||||Methods for confirming the position of the catheter tip include chest radiography, fluoroscopy, or point-of-care transthoracic echocardiography or continuous electrocardiography.

- For neonates, infants, and children, determine on a case-by-case basis whether to leave the catheter in place and obtain consultation or to remove the catheter nonsurgically
- After the injury has been evaluated and a treatment plan has been executed, confer with the surgeon regarding relative risks and benefits of proceeding with the elective surgery *versus* deferring surgery to allow for a period of patient observation

Appendix 1. Summary of Recommendations^{###}

Resource Preparation

- Perform central venous catheterization in an environment that permits use of aseptic techniques
- Ensure that a standardized equipment set is available for central venous access
- Use a checklist or protocol for placement and maintenance of central venous catheters
- Use an assistant during placement of a central venous catheter

Prevention of Infectious Complications

Intravenous Antibiotic Prophylaxis

- Do not routinely administer intravenous antibiotic prophylaxis

Aseptic Preparation

- In preparation for the placement of central venous catheters, use aseptic techniques (e.g., hand washing) and maximal barrier precautions (e.g., sterile gowns, sterile gloves, caps, masks covering both mouth and nose, full-body patient drapes, and eye protection)

Selection of Antiseptic Solution

- Use a chlorhexidine-containing solution for skin preparation in adults, infants, and children
 - For neonates, determine the use of chlorhexidine-containing solutions for skin preparation based on clinical judgment and institutional protocol
- If there is a contraindication to chlorhexidine, povidone-iodine or alcohol may be used
- Unless contraindicated, use skin preparation solutions containing alcohol

Catheters Containing Antimicrobial Agents

- For selected patients, use catheters coated with antibiotics, a combination of chlorhexidine and silver sulfadiazine, or silver-platinum-carbon-impregnated catheters based on risk of infection and anticipated duration of catheter use
 - Do not use catheters containing antimicrobial agents as a substitute for additional infection precautions

###Refer to appendix 5 for a summary of methods and analysis.

Selection of Catheter Insertion Site

- Determine catheter insertion site selection based on clinical need
- Select an insertion site that is not contaminated or potentially contaminated (e.g., burned or infected skin, inguinal area, adjacent to tracheostomy or open surgical wound)
- In adults, select an upper body insertion site when possible to minimize the risk of infection

Catheter Fixation

- Determine the use of sutures, staples, or tape for catheter fixation on a local or institutional basis
- Minimize the number of needle punctures of the skin

Insertion Site Dressings

- Use transparent bioocclusive dressings to protect the site of central venous catheter insertion from infection
- Unless contraindicated, dressings containing chlorhexidine may be used in adults, infants, and children
- For neonates, determine the use of transparent or sponge dressings containing chlorhexidine based on clinical judgment and institutional protocol
- If a chlorhexidine-containing dressing is used, observe the site daily for signs of irritation, allergy or necrosis

Catheter Maintenance

- Determine the duration of catheterization based on clinical need
- Assess the clinical need for keeping the catheter in place on a daily basis
- Remove catheters promptly when no longer deemed clinically necessary
- Inspect the catheter insertion site daily for signs of infection
- Change or remove the catheter when catheter insertion site infection is suspected
- When a catheter-related infection is suspected, a new insertion site may be used for catheter replacement rather than changing the catheter over a guidewire

Aseptic Techniques Using an Existing Central Venous Catheter for Injection or Aspiration

- Clean catheter access ports with an appropriate antiseptic (e.g., alcohol) before each access when using an existing central venous catheter for injection or aspiration
- Cap central venous catheter stopcocks or access ports when not in use
- Needleless catheter access ports may be used on a case-by-case basis

Prevention of Mechanical Trauma or Injury

Catheter Insertion Site Selection

- Determine catheter insertion site selection based on clinical need and practitioner judgment, experience, and skill
- Select an upper body insertion site when possible to minimize the risk of thrombotic complications relative to the femoral site

Positioning the Patient for Needle Insertion and Catheter Placement

- Perform central venous access in the neck or chest with the patient in the Trendelenburg position when clinically appropriate and feasible

Needle Insertion, Wire Placement, and Catheter Placement

- Select catheter size (i.e., outside diameter) and type based on the clinical situation and skill/experience of the operator
- Select the smallest size catheter appropriate for the clinical situation
- For the subclavian approach select a thin-wall needle (i.e., Seldinger) technique *versus* a catheter-over-the-needle (i.e., modified Seldinger) technique
- For the jugular or femoral approach, select a thin-wall needle or catheter-over-the-needle technique based on the clinical situation and the skill/experience of the operator
- For accessing the vein before threading a dilator or large-bore catheter, base the decision to use a thin-wall needle technique or a catheter-over-the-needle technique at least in part on the method used to confirm that the wire resides in the vein (fig. 1)****
- The number of insertion attempts should be based on clinical judgment
- The decision to place two catheters in a single vein should be made on a case-by-case basis

Guidance of Needle, Wire, and Catheter Placement

- Use real-time ultrasound guidance for vessel localization and venipuncture when the internal jugular vein is selected for cannulation (see fig. 1)†††
 - When feasible, real-time ultrasound may be used when the subclavian or femoral vein is selected
- Use static ultrasound imaging before prepping and draping for prepuncture identification of anatomy to determine vessel localization and patency when the internal jugular vein is selected for cannulation
 - Static ultrasound may also be used when the subclavian or femoral vein is selected

****The catheter over-the-needle technique may provide more stable venous access if manometry is used for venous confirmation.

†††This approach may not be feasible in emergency circumstances or in the presence of other clinical constraints.

††††For neonates, infants, and children, confirmation of venous placement may take place after the wire is threaded.

Verification of Needle, Wire, and Catheter Placement

- After insertion of a catheter that went over the needle or a thin-wall needle, confirm venous access^{§§§§}
 - Do not rely on blood color or absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein
- When using the thin-wall needle technique, confirm venous residence of the wire after the wire is threaded
 - When using the catheter-over-the-needle technique, confirmation that the wire resides in the vein may not be needed (1) when the catheter enters the vein easily and manometry or pressure-waveform measurement provides unambiguous confirmation of venous location of the catheter and (2) when the wire passes through the catheter and enters the vein without difficulty
 - If there is any uncertainty that the catheter or wire resides in the vein, confirm venous residence of the wire after the wire is threaded; insertion of a dilator or large-bore catheter may then proceed^{||||}
- After final catheterization and before use, confirm residence of the catheter in the venous system as soon as clinically appropriate^{####}
- Confirm the final position of the catheter tip as soon as clinically appropriate^{****}
 - For central venous catheters placed in the operating room, perform a chest radiograph no later than the early postoperative period to confirm the position of the catheter tip
- Verify that the wire has not been retained in the vascular system at the end of the procedure by confirming the presence of the removed wire in the procedural field
 - If the complete guidewire is not found in the procedural field, order chest radiography to determine whether the guidewire has been retained in the patient's vascular system

§§§§Methods for confirming that the catheter or thin-wall needle resides in the vein include, but are not limited to, ultrasound, manometry, or pressure-waveform analysis measurement.

|||||Methods for confirming that the wire resides in the vein include, but are not limited to, ultrasound (identification of the wire in the vein) or transesophageal echocardiography (identification of the wire in the superior vena cava or right atrium), continuous electrocardiography (identification of narrow-complex ectopy), or fluoroscopy.

####Methods for confirming that the catheter is still in the venous system after catheterization and before use include manometry or pressure-waveform measurement.

****Methods for confirming the position of the catheter tip include chest radiography, fluoroscopy, or point-of-care transthoracic echocardiography or continuous electrocardiography.

Management of Arterial Trauma or Injury Arising from Central Venous Catheterization

- When unintended cannulation of an arterial vessel with a dilator or large-bore catheter occurs, leave the dilator or catheter in place and immediately consult a general surgeon, a vascular surgeon, or an interventional radiologist regarding surgical or nonsurgical catheter removal for adults
- For neonates, infants, and children, determine on a case-by-case basis whether to leave the catheter in place and obtain consultation or to remove the catheter nonsurgically
- After the injury has been evaluated and a treatment plan has been executed, confer with the surgeon regarding relative risks and benefits of proceeding with the elective surgery *versus* deferring surgery to allow for a period of patient observation

Appendix 2. Example of a Standardized Equipment Cart for Central Venous Catheterization for Adult Patients

Item Description	Quantity
First drawer	
Bottles of alcohol-based hand cleanser	2
Transparent bioocclusive dressings with catheter stabilizer devices	2
Transducer kit: NaCl 0.9% 500-ml bag; single line transducer, pressure bag	1
Needle holder, Webster disposable 5 inch	1
Scissors, 4-1/2 inch sterile	1
Vascular access tray (chloraprep, sponges, labels)	1
Disposable pen with sterile labels	4
Sterile tubing, arterial line pressure-rated (for manometry)	2
Intravenous connector with needleless valve	4
Second drawer	
Ultrasound probe cover, sterile 3 × 96	2
Applicator, chloraprep 10.5 ml	3
Surgical hair clipper blade	3
Solution, NaCl bacteriostatic 30 ml	2
Third drawer	
Surgical hats	6
Goggles	2
Mask, surgical fluid shield	2
Gloves, sterile sizes 6.0–8.0 (2 each size)	10
Packs, sterile gowns	2
Fourth drawer	
Drape, total body (with femoral window)	1
Sheet, central line total body (no window)	1
Fifth drawer	
Dressing, sterile sponge packages	4
Catheter kit, central venous pressure single lumen 14 gauge	1
Catheter kits, central venous pressure two lumens 16 cm 7 French	2
Sixth drawer	
Triple lumen central venous catheter sets, 7 French antimicrobial-impregnated	2
Introducer catheter sets, 9 French with side port	2

Appendix 3. Example of a Central Venous Catheterization Checklist

Central Line Insertion Standard Work & Safety (Bundle) Checklist for OR and CCU		
Date: _____ Start Time: _____ End Time: _____		
Procedure Operator: _____ Person Completing Form: _____		
Catheter Type: ☐ Central Venous ☐ PA/Swan-Ganz™		
French Size of catheter: _____ Catheter lot number: _____		
Number of Lumens: ☐ 1 ☐ 2 ☐ 3 ☐ 4		
Insertion Site: ☐ Jugular ☐ Upper Arm ☐ Subclavian ☐ Femoral		
Side of Body: ☐ Left ☐ Right ☐ Bilateral		
Clinical Setting: ☐ Elective ☐ Emergent		

BEFORE	1. Consent form complete and in chart	Exception: Emergent procedure	☐
	2. Patient's Allergy Assessed (especially to Lidocaine or Heparin)		☐
	3. Patient's Latex Allergy Assessed (modify supplies)		☐
	4. Hand Hygiene: • Operator and assistant cleanse hands (ASK, if not witnessed)		☐
	5. Optimal Catheter Site Selection: • In adults, consider upper body site • Check / explain why femoral site used: _____		☐ ☐
	☐ <i>Anatomy – distorted, prior surgery/radiation. Scar</i> ☐ <i>Chest wall infection or burn</i> ☐ <i>Coagulopathy</i> ☐ <i>COPD severe/ lung disease</i> ☐ <i>Emergency / CPR</i> ☐ <i>Pediatric</i>	OR Exception(s) checked to left	
	6. Pre-procedure Ultrasound Check of internal jugular location and patency if IJ		☐
	7. Skin Prep Performed (Skin Antisepsis): • Chloraprep 10.5 ml applicator used • <u>Dry technique (normal, unbroken skin): 30 second scrub + 30 second dry time</u> • <u>Wet technique (abnormal or broken skin): 2 minute scrub + 1 minute dry time</u>		☐ ☐ DRY ☐ WET
	8. MAXIMUM Sterile Barriers: • Operator wearing hat, mask, sterile gloves, and sterile gown • Others in room wearing hats and masks, (except patient) • Patient's body covered by sterile drape		☐ ☐ ☐
	9. Procedural "Time out" Performed: • Patient ID X 2 • Procedure to be performed has been announced • Insertion site marked • Patient positioned correctly for procedure (Supine or Trendelenburg) • Assembled equipment/ supplies including venous confirmation method verified • Labels on all medication & syringes are verified		☐ ☐ ☐ ☐ ☐ ☐
	10. Ultrasound Guidance Used for Elective Internal Jugular insertions (sterile probe cover in place)		☐ Used for IJ ☐ Not used (Other site used)
11. Confirmation of Venous Placement of Access Needle or Catheter: (do not rely on blood color or presence/absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein)		☐ Manometry ☐ Ultrasound ☐ Transducer	

Appendix 3. Continued

DURING	12. Confirmation of Venous Placement of the Wire:	• Access catheter easily in vein & confirmed (catheter-over needle technique) • Access <i>via</i> thin-wall needle (confirmation of wire recommended) • or ambiguous catheter or wire placement when using catheter-over-the-needle technique	☐ Not Needed ☐ Ultrasound ☐ TEE ☐ Fluoroscopy ☐ ECG	
	13. Confirmation of Final Catheter in Venous System Prior to Use:		☐ Manometry ☐ Transducer ☐ Contrast-enhanced ultrasound	
	14. Final Steps:	• Verify guidewire not retained • Type and Dosage (ml / units) of Flush: _____ • Catheter caps placed on lumens • Final catheter tip position confirmation: Fluoroscopy Continuous ECG Transthoracic ultrasound Chest radiograph ordered • Catheter Secured / Sutured in place	☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐	
	15. Transparent Bio-occlusive dressing applied		☐	
	16. Sterile Technique Maintained when applying dressing		☐	
	17. Dressing Dated		☐	
	18. After tip location confirmed, "Approved for use" Written on Dressing		☐	
	19. Central line (maintenance) Order Placed		☐	
	AFTER	20. Dressing changed		☐
		21. Dressing removed		☐

Comments:

Tip location:

COPD, chronic obstructive pulmonary disease; CPR, cardiopulmonary resuscitation; ECG, electrocardiography; IJ, internal jugular; PA, pulmonary artery; TEE, transesophageal echocardiography.

Appendix 4. Example Duties Performed by an Assistant for Central Venous Catheterization

- Reads prompts on checklist to ensure that no safety step is forgotten or missed
- Completes checklist as task is completed
- Verbally alerts anesthesiologist if a potential error or mistake is about to be made
- Gathers equipment/supplies or brings standardized supply cart
- Brings the ultrasound machine, positions it, turns it on, makes adjustments as needed
- Provides moderate sedation (if registered nurse) if needed
- Participates in "time-out" before procedure
- Washes hands and wears mask, cap, and nonsterile gloves (scrubs or cover gown required if in the sterile envelope)
- Attends to patient requests if patient awake during procedure
- Assists with patient positioning
- Assists with draping
- Assists with sterile field setup; drops sterile items into field as needed
- Assists with sterile ultrasound sleeve application to ultrasound probe
- Assists with attachment of intravenous lines or pressure lines if needed
- Assists with application of a sterile bandage at the end of the procedure
- Assists with clean-up of patient, equipment, and supply cart; returns items to their proper location

Appendix 5: Methods and Analyses

For these updated guidelines, a systematic search and review of peer-reviewed published literature was conducted, with scientific findings summarized and reported below and in the document. Assessment of conceptual issues, practicality, and feasibility of the guideline recommendations was also evaluated, with opinion data collected from surveys and other sources. Both the systematic literature review and the opinion data are based on evidence linkages or statements regarding potential relationships between interventions and outcomes associated with central venous access. The evidence model below guided the search, providing inclusion and exclusion information regarding patients, procedures, practice settings, providers, clinical interventions, and outcomes. After review of all evidentiary information, the task force placed each recommendation into one of three categories: (1) provide the intervention or treatment, (2) the intervention or treatment may be provided to the patient based on circumstances of the case and the practitioner's clinical judgment, or (3) do not provide the intervention or treatment. The policy of the American Society of Anesthesiologists (ASA) Committee on Standards and

Practice Parameters is to update practice guidelines every 5 yr. The ASA Committee on Standards and Practice Parameters reviews all practice guidelines at the ASA annual meeting and determines update and revision timelines.

Evidence Model

Patients

- Inclusion criteria:
 - Adults
 - Children
 - Infants
 - Neonates
- Exclusion criteria:
 - None

Procedures

- Inclusion criteria:
 - Elective central venous access procedures
- Exclusion criteria:
 - Emergency central venous access procedures

Practice Settings

- Inclusion criteria:
 - Any setting where elective central venous access procedures are performed
- Exclusion criteria:
 - All other settings

Providers

- Inclusion criteria:
 - Anesthesia care providers
- Anesthesiologists
- Providers working under the direction of anesthesiologists
- Exclusion criteria:
 - Individuals who do not perform central venous catheterization

Interventions

- Inclusion criteria:
 - Resource preparation
 - Selection of a sterile environment (*e.g.*, operating room) for elective central venous catheterization
 - Availability of a standardized equipment set (*e.g.*, kit/cart/set of tools) for central venous catheterization
 - Use of a trained assistant for central venous catheterization

- Use of a checklist for central venous catheter placement and maintenance
- Prevention of infectious complications
 - Intravenous antibiotic prophylaxis
 - Aseptic techniques:
 - Aseptic preparation
 - Washing hands immediately before placement
 - Sterile full-body drapes
 - Sterile gown, gloves, mask, cap for the operators
 - Shaving hair *versus* clipping hair *versus* no hair removal
 - Remove rings, watches
 - Skin preparation solution
 - Chlorhexidine *versus* povidone–iodine
 - Skin preparation with *versus* without alcohol
 - Selection of catheter type
 - Antibiotic-coated catheters *versus* no coating
 - Silver-impregnated catheters *versus* no coating
 - Heparin-coated catheters *versus* no coating
 - Antibiotic-coated or silver-impregnated catheter cuffs
 - Selection of catheter insertion site
 - External jugular
 - Internal jugular
 - Subclavian
 - Femoral
 - Selecting an insertion site that is not contaminated or potentially contaminated (*e.g.*, burned or infected skin, a site adjacent to a tracheostomy site)
 - Catheter fixation
 - Suture *versus* staple
 - Suture *versus* tape
 - Staple *versus* tape
 - Sterile dressing type
 - Clear plastic
 - Chlorhexidine
 - Gauze and tape
 - Dermabond
 - Biopatch
 - Antibiotic ointment
 - Catheter maintenance:
 - Long-term *versus* short-term catheterization
 - Frequency of assessing the necessity of retaining access
 - Frequency of insertion site inspection for signs of infection
 - Time intervals for changing catheters
 - At specified time intervals *versus* no specified time intervals
 - One specified time interval *versus* another time interval
 - Changing a catheter site

- Changing over a wire *versus* a new catheter at a new site
 - Injecting or aspirating using an existing central venous catheter
 - Aseptic techniques (*e.g.*, wiping port with alcohol)
 - Not using stopcocks
 - Prevention of mechanical trauma or injury:
 - Selection of catheter insertion site
 - External jugular
 - Internal jugular
 - Subclavian
 - Femoral
 - Patient preparation for needle insertion and catheter placement
 - Awake *versus* anesthetized patient during insertion
 - Positive pressure (*i.e.*, mechanical) *versus* spontaneous ventilation during insertion
 - Patient position: Trendelenburg *versus* supine
 - Prepuncture identification of anatomy
 - Surface landmark inspection to identify target vein
 - Needle insertion and catheter placement
 - Catheter selection
 - Selection of catheter diameter
 - Selection of catheter composition (*e.g.*, polyvinyl chloride, polyethylene, Teflon)
 - Selection of catheter type (all types will be compared with each other)
 - Single lumen
 - Double lumen
 - Triple lumen
 - Cordis (side arm introducer sheath)
 - Use of a finder (seeker) needle *versus* no seeker needle (*e.g.*, a wider-gauge access needle)
 - Use of a thin-wall needle *versus* a cannula over a needle before insertion of a wire for the Seldinger technique
 - Placement of two lines in the same vein
 - Limiting number of insertion attempts
 - Use of a vessel dilator
 - Monitoring for needle, wire, and catheter placement
 - Ultrasound (including audio-guided Doppler ultrasound)
 - Prepuncture identification of insertion site *versus* no ultrasound
 - Guidance during needle puncture and placement *versus* no ultrasound
 - Confirmation of venous insertion of needle
 - Confirmation of venous placement of wire
 - Confirmation of catheter tip location
 - Identification of free aspiration of dark (PO₂) nonpulsatile blood
 - Confirmation of venous placement of catheter
 - Venous blood gas
 - Confirmation of venous placement of catheter
 - Manometry *versus* direct pressure measurement (*via* pressure transducer)
 - Confirmation of venous placement of catheter
 - Continuous EKG
 - Confirmation of wire placement
 - Confirmation of catheter tip location
 - Fluoroscopy
 - Confirmation of venous placement of wire
 - Confirmation of catheter tip location
 - X-rays
 - Confirmation of catheter tip location
 - Timing of x-ray immediately after placement *versus* postop
 - Real-time transthoracic echocardiography
- Management of trauma or injury arising from central venous catheterization:
 - Management of arterial cannulation, arterial injury, or cerebral embolization
 - Pulling out a catheter from the carotid artery *versus* the subclavian artery
 - Immediate removal *versus* retaining catheter until a vascular surgery consult is obtained
 - Management of catheter or wire shearing or loss
 - Interventional radiology consultation
 - Management of hemo/pneumothorax; retroperitoneal bleeding after femoral catheterization
 - Volume replacement
 - Chest tube
 - Serial hematocrit measurement
 - Management of tamponade
 - Fluid resuscitation
 - Pericardiocentesis
 - Surgical consultation
 - Management of wire knot, wire, or catheter that will not come out
 - Interventional radiology consultation
 - Management of tracheal injury
 - Thoracic surgery consultation
 - ENT consultation
 - Management of air embolism
 - Aspiration
 - Vasoactive medication

- Volume therapy
- Hyperbaric therapy
- Management of phrenic nerve injury
 - Neurology consultation
- Management of neck hematoma
 - Airway protection
- Management of thromboembolism during removal
 - Anticoagulation
 - Vascular surgery consultation
 - Neurosurgery surgery consultation
- Exclusion criteria:
 - Arterial (pulmonary artery) catheters
 - Floatation and residence (*i.e.*, maintenance) issues of a pulmonary artery catheter
 - Central venous catheters *versus* other methods of assessing volume status or presence of tamponade/pericarditis (*e.g.*, pulse pressure variability and echo)
 - Clinical indications for placement of central venous catheters
 - Detection and treatment of infectious complications
 - Dialysis catheters
 - Education, training, and certification of providers
 - Monitoring central line pressure waveforms and pressures
 - Nursing care
 - Pacing catheters
 - Peripheral IV insertion and care
 - Peripherally inserted percutaneous intravenous central catheter (PICC line) placement for long-term use (*e.g.*, chemotherapy regimens, antibiotic therapy, total parenteral nutrition, chronic vasoactive agent administration, *etc.*)
 - Tunneled catheters (*e.g.*, Hickman, Quinton, permacaths, portacaths)

Outcomes

- Inclusion criteria:
 - Arterial cannulation/injury/cerebral embolization/hemorrhage
 - Catheter or wire shearing or loss
 - Hemo/pneumothorax; peritoneal hemorrhage
 - Tamponade
 - Wire, knot, inability to remove the catheter
 - Tracheal injury
 - Air embolism
 - Phrenic nerve injury
 - Bloodstream infections
 - Exsanguination
 - Failed insertion attempts
 - Heart puncture (tamponade)
 - Hemothorax
 - Hospital costs
 - Hospital, intensive care unit length of stay

- Infections
- Lacerations of great vessels
- Catheter colonization
- Mortality
- Number of attempts at central line placement
- Patient satisfaction
- Pneumothorax
- Procedural efficiency
- Sepsis
- Stroke
- Successful, nontraumatic procedure
- Time required for placement of central venous catheters
- Venous and arterial air embolism
- Wire, needle, catheter injury
- Exclusion criteria:
 - Infections or other complications not associated with central venous catheterization
 - Mechanical injury or trauma not associated with central venous catheterization

Evidence Collection

- Literature inclusion criteria:
 - Randomized controlled trials (RCTs)
 - Prospective nonrandomized comparative studies (*e.g.*, quasiexperimental, cohort)
 - Retrospective comparative studies (*e.g.*, case-control)
 - Observational studies (*e.g.*, correlational or descriptive statistics)
 - Case reports, case series
- Literature exclusion criteria (except to obtain new citations):
 - Editorials
 - Literature reviews
 - Meta-analyses conducted by others
 - Unpublished studies
 - Studies in non-peer-reviewed journals
 - Newspaper articles
- Survey evidence:
 - Expert consultant survey
 - ASA membership survey
 - Other participating organization surveys
 - Reliability survey
 - Feasibility survey

State of the Literature. For the systematic review, potentially relevant clinical studies were identified *via* electronic and manual searches. Bibliographic database searches included PubMed and EMBASE. The searches covered an 8.3-yr period from January 1, 2011, through April 30, 2019. Citation searching (backward and forward) of relevant meta-analyses and other systematic reviews was also performed; pre-2011 studies relevant to meta-analyses or use of ultrasound were

eligible for inclusion. No search for gray literature was conducted. Publications identified by task force members were also considered. Accepted studies from the previous guidelines were also rereviewed, covering the period of January 1, 1971, through June 31, 2011. Only studies containing original findings from peer-reviewed journals were acceptable. Editorials, letters, and other articles without data were excluded. A literature search strategy and PRISMA* flow diagram are available as Supplemental Digital Content 2 (<http://links.lww.com/ALN/C7>). In total, 4,491 unique new citations were identified, with 1,013 full articles assessed for eligibility. After review, 729 were excluded, with 284 new studies meeting inclusion criteria. These studies were combined with 258 pre-2011 articles from the previous guidelines, resulting in a total of 542 articles accepted as evidence for these guidelines. In this document, 249 are referenced, with a complete bibliography of articles used to develop these guidelines, organized by section, available as Supplemental Digital Content 3 (<http://links.lww.com/ALN/C8>).

Each pertinent outcome reported in a study was classified by evidence category and level and designated as beneficial, harmful, or equivocal. Findings were then summarized for each evidence linkage and reported in the text of the updated Guideline, with summary evidence tables available as Supplemental Digital Content 4 (<http://links.lww.com/ALN/C9>).

Evidence categories refer specifically to the strength and quality of the research design of the studies. Category A evidence represents results obtained from RCTs, and category B evidence represents observational results obtained from nonrandomized study designs or RCTs without pertinent comparison groups. When available, category A evidence is given precedence over category B evidence for any particular outcome. These evidence categories are further divided into evidence levels. Evidence levels refer specifically to the strength and quality of the summarized study findings (*i.e.*, statistical findings, type of data, and the number of studies reporting/replicating the findings). In this document, only the highest level of evidence is included in the summary report for each intervention—outcome pair, including a directional designation of benefit, harm, or equivocality.

Category A: RCTs report comparative findings between clinical interventions for specified outcomes. Statistically significant ($P < 0.01$) outcomes are designated as either beneficial (B) or harmful (H) for the patient; statistically nonsignificant findings are designated as equivocal (E).

Level 1: The literature contains a sufficient number of RCTs to conduct meta-analysis,^{††††} and meta-analytic findings from these aggregated studies are reported as evidence.

Level 2: The literature contains multiple RCTs, but the number of RCTs is not sufficient to conduct a viable meta-analysis for the purpose of these Guidelines. Findings from these RCTs are reported separately as evidence.

Level 3: The literature contains a single RCT, and findings from this study are reported as evidence.

Category B: Observational studies or RCTs without pertinent comparison groups may permit inference of beneficial or harmful relationships among clinical interventions and clinical outcomes. Inferred findings are given a directional designation of beneficial (B), harmful (H), or equivocal (E). For studies that report statistical findings, the threshold for significance is $P < 0.01$.

Level 1: The literature contains nonrandomized comparisons (*e.g.*, quasiexperimental, cohort [prospective or retrospective], or case-control research designs) with comparative statistics between clinical interventions for a specified clinical outcome.

Level 2: The literature contains noncomparative observational studies with associative statistics (*e.g.*, correlation, sensitivity, and specificity).

Level 3: The literature contains noncomparative observational studies with descriptive statistics (*e.g.*, frequencies, percentages).

Level 4: The literature contains case reports.

Insufficient Literature. The lack of sufficient scientific evidence in the literature may occur when the evidence is either unavailable (*i.e.*, no pertinent studies found) or inadequate. Inadequate literature cannot be used to assess relationships among clinical interventions and outcomes because a clear interpretation of findings is not obtained due to methodological concerns (*e.g.*, confounding of study design or implementation) or the study does not meet the criteria for content as defined in the “Focus” of the guidelines.

The literature relating to seven evidence linkages contained enough studies with well defined experimental designs and statistical information to conduct formal meta-analyses (table 1). These seven evidence linkages are: (1) antimicrobial catheters, (2) silver impregnated catheters, (3) chlorhexidine and silver-sulfadiazine catheters, (4) dressings containing chlorhexidine, and (5) ultrasound guidance for venipuncture. For meta-analyses of antimicrobial, silver, or silver-sulfadiazine catheters studies reported actual event rates and odds ratios were pooled. Because not all studies of dressings reported event rates, relative risks or hazard ratios (recognizing they approximate relative risks) were pooled. Ultrasound guidance outcomes were pooled using risk or mean differences (continuous outcomes) for clinical relevance. Fixed-effects models were fitted using Mantel-Haenszel or inverse variance weighting as appropriate. Random-effects models were fitted with inverse variance weighting using the DerSimonian and Laird estimate of between-study variance. Small study effects

†††††All meta-analyses are conducted by the ASA methodology group. Meta-analyses from other sources are reviewed but not included as evidence in this document. A minimum of five independent RCTs (*i.e.*, sufficient for fitting a random-effects model²⁵⁹) is required for meta-analysis.

(including potential publication bias) were explored by examining forest and funnel plots, regression tests, trim-and-fill results, and limit meta-analysis. Sensitivity to effect measure was also examined. Heterogeneity was quantified with I^2 and prediction intervals estimated (see table 1). Analyses were conducted in R version 3.5.3²⁵⁶ using the Meta²⁵⁷ and Metasens²⁵⁸ packages. A significance level of $P < 0.01$ was applied for analyses.

Although interobserver agreement among task force members and two methodologists was not assessed for this update, the original guidelines reported agreement levels using a κ statistic for two-rater agreement pairs as follows: (1) research design, $\kappa = 0.70$ to 1.00 ; (2) type of analysis, $\kappa = 0.60$ to 0.84 ; (3) evidence linkage assignment, $\kappa = 0.91$ to 1.00 ; and (4) literature inclusion for database, $\kappa = 0.28$ to 1.00 . Three-rater κ values between two methodologists and task force reviewers were: (1) research design, $\kappa = 0.70$; (2) type of analysis, $\kappa = 0.68$; (3) linkage assignment, $\kappa = 0.79$; and (4) literature database inclusion, $\kappa = 0.65$. These values represented moderate to high levels of agreement.

Consensus-based Evidence

Validation of the concepts addressed by these guidelines and subsequent recommendations proposed was obtained by consensus from multiple sources, including: (1) survey opinion from consultants^{####} who were selected based on their knowledge or expertise in central venous access (2) survey opinions from a randomly selected sample of active members of the ASA; (3) testimony from attendees of publicly held open forums for the original guidelines at a national anesthesia meeting^{#####}; and (4) internet commentary. All opinion-based evidence relevant to each topic was considered in the development of these guidelines. However, only findings obtained from formal surveys are reported in the document. Opinion surveys were developed by the task force to address each clinical intervention identified in the document. Identical surveys were distributed to expert consultants and a random sample of members of the participating organizations.

Survey responses were recorded using a 5-point scale and summarized based on median values.^{#####}

Strongly agree: Median score of 5 (at least 50% of the responses are 5)

Agree: Median score of 4 (at least 50% of the responses are 4 or 4 and 5)

Equivocal: Median score of 3 (at least 50% of the responses are 3, or no other response category or combination of similar categories contain at least 50% of the responses)

Disagree: Median score of 2 (at least 50% of responses are 2 or 1 and 2)

Strongly disagree: Median score of 1 (at least 50% of responses are 1)

The rate of return for the survey addressing guideline recommendations was 37% ($n = 40$ of 109) for consultants. For membership respondents, the survey rate of return was 8% ($n = 393$ of 5,000) members. The results of the surveys are reported in tables 2 and 3 and are summarized in the text of the guidelines.^{#####}

An additional survey was sent to the consultants accompanied by a draft of the guidelines asking them to indicate which, if any, of the recommendations would change their clinical practices if the guidelines were instituted. The rate of return was 17.4% ($n = 19$ of 109). The percentage of responding consultants expecting *no change* associated with each linkage were as follows: (1) resource preparation (environment with aseptic techniques, standardized equipment set) = 89.5%; (2) use of a trained assistant = 100%; (3) use of a checklist or protocol for placement and maintenance = 89.5%; (4) aseptic preparation (hand washing, sterile full-body drapes, etc.) = 100%; (5) selection of antiseptic solution for skin preparation = 100%; (6) catheters with antibiotic or antiseptic coatings/impregnation = 68.5%; (7) catheter insertion site selection (for prevention of infectious complications) = 100%; (8) catheter fixation methods (sutures, staples, tape) = 100%; (9) insertion site dressings = 100%; (10) catheter maintenance (insertion site inspection, changing catheters) = 100%; (11) aseptic techniques using an existing central line for injection or aspiration = 100%; (12) selection of catheter insertion site (for prevention of mechanical trauma) = 100%; (13) positioning the patient for needle insertion and catheter placement = 100%; (14) needle insertion, wire placement, and catheter placement (catheter size, type) = 100%; (15) guiding needle, wire, and catheter placement (ultrasound) = 100%; (16) verifying needle, wire, and catheter placement = 100%; (17) confirmation of final catheter tip location = 89.5%; and (18) management of trauma or injury arising from central venous catheterization = 100%.

Of the respondents, 82% indicated that the guidelines would have no effect on the amount of time spent on a typical case, and 17.6% indicated that there would be an increase of the amount of time spent on a typical case with the implementation of these guidelines. No respondents indicated that new equipment, supplies, or training would not be needed to implement the guidelines, and 88.9% indicated that implementation of the guidelines would not require changes in practice that would affect costs.

Consultants were drawn from the following specialties where central venous access is a concern: anesthesiology (97% of respondents) and critical care (3% of respondents).

Society for Pediatric Anesthesia Winter Meeting, April 17, 2010, San Antonio, Texas; Society of Cardiovascular Anesthesia 32nd Annual Meeting, April 25, 2010, New Orleans, Louisiana; and International Anesthesia Research Society Annual Meeting, May 22, 2011, Vancouver, British Columbia, Canada.

When an equal number of categorically distinct responses are obtained, the median value is determined by calculating the arithmetic mean of the two middle values. Ties are calculated by a predetermined formula.

To view a bar chart with the above findings, refer to Supplemental Digital Content 5 (<http://links.lww.com/ALN/C10>).

Table 1. Meta-analysis Summary

Evidence Linkages*	Studies†	Patients	Effect				Heterogeneity	
			Fixed	P	Random	P	I²	P‡
Impregnated <i>versus</i> uncoated catheters								
Colonization			Odds Ratio (99% CI)§					
Antibiotic ^{78–85}	8	1,262	0.27 (0.18 to 0.40)	< 0.001	0.27 (0.15 to 0.46)	< 0.001	29%	0.20
Chlorhexidine silver sulfadiazine ^{83,95,100–118}	21	4,819	0.50 (0.41 to 0.61)	< 0.001	0.49 (0.37 to 0.65)	< 0.001	46%	0.013
Silver or silver-platinum-carbon ^{87–97}	11	3,091	0.98 (0.79 to 1.23)	0.85	0.98 (0.79 to 1.23)	0.85	0%	0.48
Catheter-related bloodstream infection								
Antibiotic ^{72,80,83,85,86}	5	1,921	0.29 (0.12 to 0.74)	< 0.001	0.33 (0.13 to 0.85)	0.003	0%	0.68
Chlorhexidine silver sulfadiazine ^{83,100–102,104–110,112–117,119,120}	19	4,931	0.69 (0.48 to 1.00)	0.01	0.69 (0.44 to 1.08)¶	0.032	18%	0.23
Silver or silver-platinum-carbon ^{87–94,96–99}	12	3,276	0.59 (0.38 to 0.92)	0.002	0.59 (0.37 to 0.94)	0.003	0%	0.66
Chlorhexidine <i>versus</i> conventional dressing			Relative Risk (99% CI)					
Colonization ^{90–133}	7	4,786	0.47 (0.38 to 0.59)	< 0.001	0.53 (0.35 to 0.81)	< 0.001	57%	0.031
Bloodstream infection ^{90,133–140}	9	6,000	0.61 (0.39 to 0.95)	0.005	0.62 (0.35 to 1.09)	0.03	26%	0.21
Real-time ultrasound <i>versus</i> landmark (internal jugular)								
			Risk Difference (99% CI)¶					
Overall success ^{186,187,189–192,194–204}	17	3,488	8.6% (6.6% to 10.5%)	< 0.001	10.0% (4.8% to 15.1%)††	< 0.001	85%	0.001
First attempt success ^{186–197}	12	2,096	30.7% (25.9% to 35.5%)	< 0.001	30.1% (18.5% to 41.6%)	< 0.001	80%	< 0.001
Arterial puncture ^{186–188,190–201,203,205}	17	3,678	–0.7.0% (0.89% to –0.5%)	< 0.001	–6.9% (–9.9% to –3.9%)	< 0.001	49%	0.012
			Mean Difference (99% CI)					
Mean attempts ^{188,190,191,194–197,199,200,203–205}	12	3,123	–0.85 (–0.94 to –0.77)	< 0.001	0.70 (0.47 to 1.02)	< 0.001	29%	< 0.001
Static ultrasound <i>versus</i> landmark								
			Risk Difference (99% CI)¶					
Internal jugular/subclavian/femoral								
Overall success ^{182,190,202,210–212}	6	1,439	3.1% (–1.3% to 7.6%)	0.067	5.3% (–1.8% to 12.5%)	0.053	54%	0.054
Arterial puncture ^{190,202,210–212}	5	618	–2.4% (–7.8% to 2.9%)	0.24	–2.5% (–11.0% to 6.1%)	0.46	56%	0.057
Internal jugular								
Overall success ^{190,202,210–212}	5	592	7.4% (0.7% to 14.1%)	0.005	7.7% (–2.0% to 17.3%)	0.041	51%	0.085

*Evidence linkage with references for included studies. †Number of studies included in the meta-analysis. ‡Statistical significance values for heterogeneity of effect size; a *P* value of <0.01 indicates that the studies are significantly heterogeneous. §Continuity correction of 0.5 for zero cell frequencies. ||Small study effects (potential for publication bias).

Table 2. Expert Consultant Survey Results

Recommendations	N	Strongly Agree,	Agree,	Equivocal,	Disagree,	Strongly Disagree,
		%	%	%	%	%
Resource preparation						
1. Perform central venous catheterization in an environment that permits use of aseptic techniques	40	95*	5	0	0	0
2. Ensure that a standardized equipment set is available for central venous access	39	77*	18	5	0	0
3. Use a checklist or protocol for placement and maintenance of central venous catheters	38	60*	26	8	5	0
4. Use an assistant during placement of a central venous catheter	40	42	28*	23	8	0
Prevention of infections complications						
Intravenous antibiotic prophylaxis						
5. For immunocompromised patients and high-risk neonates, administer intravenous antibiotic prophylaxis on a case-by-case basis	40	12	30	40*	18	0
6. Do not routinely administer intravenous antibiotic prophylaxis	40	55*	38	8	0	0
Aseptic preparation						
7. In preparation for the placement of central venous catheters, use aseptic techniques (<i>e.g.</i> , hand washing) and maximal barrier precautions (<i>e.g.</i> , sterile gowns, sterile gloves, caps, masks covering both mouth and nose, and full-body patient drapes)	39	74*	21	3	3	0
Selection of antiseptic solution						
8. Use a chlorhexidine-containing solution for skin preparation in adults, infants, and children	39	85*	15	0	0	0
9. For neonates, determine the use of chlorhexidine-containing solutions for skin preparation based on clinical judgment and institutional protocol	38	42	40*	18	0	0
10. If there is a contraindication to chlorhexidine, povidone-iodine or alcohol may be used	39	59*	36	5	0	0
11. Unless contraindicated, use skin preparation solutions containing alcohol	39	28	39*	23	10	0
Catheters containing antimicrobial agents						
12. For selected patients, use catheters coated with antibiotics or a combination of chlorhexidine and silver sulfadiazine based on infectious risk, cost, and anticipated duration of catheter use	38	29	40*	24	8	0
13. Do not use catheters containing antimicrobial agents as a substitute for additional infection precautions	38	63*	18	16	3	0

(Continued)

Table 2. (Continued)

Recommendations	N	Strongly Agree, %	Agree, %	Equivocal, %	Disagree, %	Strongly Disagree, %
14. Determine catheter insertion site selection based on clinical need	38	71*	29	0	0	0
15. Select an insertion site that is not contaminated or potentially contaminated (<i>e.g.</i> , burned or infected skin, inguinal area, adjacent to tracheostomy or open surgical wound)	38	82*	16	3	0	0
16. To minimize the risk of infection in adults, select an upper body insertion site when possible	38	76*	21	3	0	0
Catheter fixation						
17. Determine the use of sutures, staples, or tape for catheter fixation on a local or institutional basis	38	47*	32	8	13	0
18. Minimize the number of needle punctures of the skin	38	61*	32	8	0	0
Insertion site dressings						
19. Use transparent bioocclusive dressings to protect the site of central venous catheter insertion from infection	38	71*	29	0	0	0
20. Unless contraindicated, dressings containing chlorhexidine may be used in adults, infants, and children	38	45	37*	18	0	0
21. For neonates, determine the use of transparent or sponge dressings containing chlorhexidine based on clinical judgment and institutional protocol	38	37	47*	13	3	0
22. If a chlorhexidine-containing dressing is used, observe the site daily for signs of irritation, allergy, or necrosis	38	66*	26	8	0	0
Catheter maintenance						
23. Determine the duration of catheterization based on clinical need	38	79*	21	0	0	0
24. Assess the clinical need for keeping the catheter in place on a daily basis	38	87*	13	0	0	0
25. Remove catheters promptly when no longer deemed clinically necessary	38	90*	11	0	0	0
26. Inspect the catheter insertion site daily for signs of infection	38	92*	8	0	0	0
27. Change or remove the catheter when catheter insertion site infection is suspected	38	66*	32	0	3	0
28. When a catheter-related infection is suspected, replace the catheter using a new insertion site rather than changing the catheter over a guidewire	38	61*	34	3	3	0
Aseptic techniques using an existing central venous catheter for injection or aspiration						
29. Wipe catheter access ports with an appropriate antiseptic (<i>e.g.</i> , alcohol) before each access when using an existing central venous catheter for injection or aspiration	38	90*	8	3	0	0
30. Cap central venous catheter stopcocks or access ports when not in use	38	79*	18	3	0	0
31. Needleless catheter access ports may be used on a case-by-case basis	38	24	53*	13	11	0
Prevention of mechanical trauma or injury						
Catheter insertion site selection						
32. Determine catheter insertion site selection based on clinical need and practitioner judgment, experience, and skill	38	68*	26	3	3	0
33. Selection of an upper body insertion site may minimize the risk of thrombotic complications relative to the femoral site	38	21	47*	26	5	0
Positioning the patient for needle insertion and catheter placement						
34. When clinically appropriate and feasible, perform central venous access in the neck or chest with the patient in the Trendelenburg position	38	53*	34	11	3	0
Needle insertion, wire placement, and catheter placement						
35. Select catheter size (<i>i.e.</i> , outside diameter) and type based on the clinical situation and skill/experience of the operator	38	63*	32	5	0	0
36. Select the smallest size catheter appropriate for the clinical situation	38	40	42*	18	0	0
37. For the subclavian approach select a thin-wall needle (<i>i.e.</i> , Seldinger) technique <i>versus</i> a catheter-over-the-needle (<i>i.e.</i> , modified Seldinger) technique	38	32	50*	18	0	0
38. For the jugular or femoral approach, select a thin-wall needle or catheter-over-the-needle technique based on the clinical situation and the skill/experience of the operator	38	32	42*	18	8	0
39. Base the decision to use a thin-wall needle technique or a catheter-over-the-needle technique at least in part on the method used to confirm that the wire resides in the vein before a dilator or large-bore catheter is threaded	38	34	50*	11	5	0
40. The number of insertion attempts should be based on clinical judgment; the decision to place two catheters in a single vein should be made on a case-by-case basis	38	42	47*	8	3	0
Guidance of needle, wire, and catheter placement						
41. Use static ultrasound imaging before prepping and draping for prepuncture identification of anatomy to determine vessel localization and patency when the internal jugular vein is selected for cannulation	36	56*	19	22	3	0
42. Static ultrasound may also be used when the subclavian or femoral vein is selected	36	39	47*	11	3	0
43. Use real-time ultrasound guidance for vessel localization and venipuncture when the internal jugular vein is selected for cannulation	36	67*	31	0	3	0
44. When feasible, real-time ultrasound may be used when the subclavian or femoral vein is selected	36	44	50*	3	3	0
Verification of needle, wire, and catheter placement						

(Continued)

Table 2. (Continued)

Recommendations	N	Strongly Agree, %	Agree, %	Equivocal, %	Disagree, %	Strongly Disagree, %
45. After insertion of a catheter that went over the needle or a thin-wall needle, confirm venous access	35	83*	14	0	3	0
46. Do not rely on blood color or absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein	35	57*	26	14	3	0
47. When using the thin-wall needle technique, confirm venous residence of the wire after the wire is threaded	35	57*	37	6	0	0
48. When using the catheter-over-the-needle technique, confirmation that the wire resides in the vein may not be needed (1) when the catheter enters the vein easily and manometry or pressure-wave-form measurement provides unambiguous confirmation of venous location of the catheter and (2) when the wire passes through the catheter and enters the vein without difficulty	35	9	40	20*	14	17
49. If there is any uncertainty that the catheter or wire resides in the vein, confirm venous residence of the wire after the wire is threaded; insertion of a dilator or large-bore catheter may then proceed	34	47	44*	3	0	6
50. After final catheterization and before use, confirm residence of the catheter in the venous system as soon as clinically appropriate	35	63*	34	3	0	0
51. Confirm the final position of the catheter tip as soon as clinically appropriate	35	60*	31	6	3	0
52. For central venous catheters placed in the operating room, perform a chest radiograph no later than the early postoperative period to confirm the position of the catheter tip	35	60*	26	14	0	0
53. Verify that the wire has not been retained in the vascular system at the end of the procedure by confirming the presence of the removed wire in the procedural field	35	74*	20	6	0	0
54. If the complete guidewire is not found in the procedural field, order chest radiography to determine whether the guidewire has been retained in the patient's vascular system	35	77*	23	0	0	0
Management of arterial trauma or injury arising from central venous catheterization						
55. When unintended cannulation of an arterial vessel with a dilator or large-bore catheter occurs, leave the dilator or catheter in place and immediately consult a general surgeon, a vascular surgeon, or an interventional radiologist regarding surgical or nonsurgical catheter removal for adults	35	57*	31	11	0	0
56. For neonates, infants, and children, determine on a case-by-case basis whether to leave the catheter in place and obtain consultation or to remove the catheter nonsurgically	34	21	47*	27	6	0
57. After the injury has been evaluated and a treatment plan has been executed, confer with the surgeon regarding relative risks and benefits of proceeding with the elective surgery <i>versus</i> deferring surgery to allow for a period of patient observation	35	66*	31	3	0	0

N = number of members who responded to each item.

*Median.

Table 3. American Society of Anesthesiologists Member Survey Results

Recommendations	N	Strongly Agree, %	Agree, %	Equivocal, %	Disagree, %	Strongly Disagree, %
Resource preparation						
1. Perform central venous catheterization in an environment that permits use of aseptic techniques	393	88*	11	1	0	0
2. Ensure that a standardized equipment set is available for central venous access	390	80*	16	3	1	0
3. Use a checklist or protocol for placement and maintenance of central venous catheters	387	50	28*	19	3	1
4. Use an assistant during placement of a central venous catheter	391	26	28*	30	13	3
Prevention of infections complications						
Intravenous antibiotic prophylaxis						
5. For immunocompromised patients and high-risk neonates, administer intravenous antibiotic prophylaxis on a case-by-case basis	381	13	28	39*	15	4
6. Do not routinely administer intravenous antibiotic prophylaxis	382	43	35*	15	5	2
Aseptic preparation						
7. In preparation for the placement of central venous catheters, use aseptic techniques (e.g., hand washing) and maximal barrier precautions (e.g., sterile gowns, sterile gloves, caps, masks covering both mouth and nose, and full-body patient drapes)	379	81*	15	2	2	0

(Continued)

Table 3. (Continued)

Recommendations	N	Strongly Agree, %	Agree, %	Equivocal, %	Disagree, %	Strongly Disagree, %
8. Use a chlorhexidine-containing solution for skin preparation in adults, infants, and children	369	79*	17	4	1	0
9. For neonates, determine the use of chlorhexidine-containing solutions for skin preparation based on clinical judgment and institutional protocol	362	22	37*	38	2	1
10. If there is a contraindication to chlorhexidine, povidone–iodine or alcohol may be used	366	48	46*	5	1	0
11. Unless contraindicated, use skin preparation solutions containing alcohol	368	36	35*	25	5	1
Catheters containing antimicrobial agents						
12. For selected patients, use catheters coated with antibiotics or a combination of chlorhexidine and silver sulfadiazine based on infectious risk, cost, and anticipated duration of catheter use	357	32	37*	24	7	0
13. Do not use catheters containing antimicrobial agents as a substitute for additional infection precautions	358	45	25*	20	8	3
Selection of catheter insertion site						
14. Determine catheter insertion site selection based on clinical need	348	55*	40	4	1	0
15. Select an insertion site that is not contaminated or potentially contaminated (<i>e.g.</i> , burned or infected skin, inguinal area, adjacent to tracheostomy or open surgical wound)	349	72*	26	2	0	0
16. To minimize the risk of infection in adults, select an upper body insertion site when possible	349	71*	26	3	0	0
Catheter fixation						
17. Determine the use of sutures, staples, or tape for catheter fixation on a local or institutional basis	344	29	44*	14	11	2
18. Minimize the number of needle punctures of the skin	345	52*	38	9	1	0
Insertion site dressings						
19. Use transparent bioocclusive dressings to protect the site of central venous catheter insertion from infection	338	70*	27	2	0	0
20. Unless contraindicated, dressings containing chlorhexidine may be used in adults, infants, and children	337	38	37*	22	2	0
21. For neonates, determine the use of transparent or sponge dressings containing chlorhexidine based on clinical judgment and institutional protocol	330	22	34*	43	1	0
22. If a chlorhexidine-containing dressing is used, observe the site daily for signs of irritation, allergy, or necrosis	337	59*	34	7	1	0
Catheter maintenance						
23. Determine the duration of catheterization based on clinical need	328	61*	35	2	1	0
24. Assess the clinical need for keeping the catheter in place on a daily basis	327	75*	22	2	1	0
25. Remove catheters promptly when no longer deemed clinically necessary	326	82*	17	2	0	0
26. Inspect the catheter insertion site daily for signs of infection	324	84*	14	2	0	0
27. Change or remove the catheter when catheter insertion site infection is suspected	328	82*	15	2	0	0
28. When a catheter-related infection is suspected, replace the catheter using a new insertion site rather than changing the catheter over a guidewire	328	70*	24	5	1	0
Aseptic techniques using an existing central venous catheter for injection or aspiration						
29. Wipe catheter access ports with an appropriate antiseptic (<i>e.g.</i> , alcohol) before each access when using an existing central venous catheter for injection or aspiration	317	78*	19	3	1	0
30. Cap central venous catheter stopcocks or access ports when not in use	316	79*	17	4	0	0
31. Needleless catheter access ports may be used on a case-by-case basis	318	43	39*	15	2	1
Prevention of mechanical trauma or injury						
Catheter insertion site selection						
32. Determine catheter insertion site selection based on clinical need and practitioner judgment, experience, and skill	314	76*	23	1	0	0
33. Selection of an upper body insertion site may minimize the risk of thrombotic complications relative to the femoral site	314	50*	39	10	1	0
Positioning the patient for needle insertion and catheter placement						
34. When clinically appropriate and feasible, perform central venous access in the neck or chest with the patient in the Trendelenburg position	308	65*	32	3	1	0
Needle insertion, wire placement, and catheter placement						
35. Select catheter size (<i>i.e.</i> , outside diameter) and type based on the clinical situation and skill/experience of the operator	301	63*	32	4	2	0
36. Select the smallest size catheter appropriate for the clinical situation	301	37	38*	19	6	0

(Continued)

Table 3. (Continued)

Recommendations	N	Strongly Agree, %	Agree, %	Equivocal, %	Disagree, %	Strongly Disagree, %
38. For the jugular or femoral approach, select a thin-wall needle or catheter-over-the-needle technique based on the clinical situation and the skill/experience of the operator	298	39	36*	20	3	3
39. Base the decision to use a thin-wall needle technique or a catheter-over-the-needle technique least in part on the method used to confirm that the wire resides in the vein before a dilator or large-bore catheter is threaded	300	40	33*	23	3	1
40. The number of insertion attempts should be based on clinical judgment; the decision to place two catheters in a single vein should be made on a case-by-case basis	301	54*	36	7	2	0
Guidance of needle, wire, and catheter placement						
41. Use static ultrasound imaging before prepping and draping for prepuncture identification of anatomy to determine vessel localization and patency when the internal jugular vein is selected for cannulation	295	34	31*	21	10	4
42. Static ultrasound may also be used when the subclavian or femoral vein is selected	294	28	43*	23	4	2
43. Use real-time ultrasound guidance for vessel localization and venipuncture when the internal jugular vein is selected for cannulation	293	59*	18	18	2	3
44. When feasible, real-time ultrasound may be used when the subclavian or femoral vein is selected	294	45	34*	18	2	1
Verification of needle, wire, and catheter placement						
45. After insertion of a catheter that went over the needle or a thin-wall needle, confirm venous access	283	75*	20	4	1	0
46. Do not rely on blood color or absence of pulsatile flow for confirming that the catheter or thin-wall needle resides in the vein	285	55*	29	11	6	0
47. When using the thin-wall needle technique, confirm venous residence of the wire after the wire is threaded	281	49	29*	17	4	0
48. When using the catheter-over-the-needle technique, confirmation that the wire resides in the vein may not be needed (1) when the catheter enters the vein easily and manometry or pressure-waveform measurement provides unambiguous confirmation of venous location of the catheter and (2) when the wire passes through the catheter and enters the vein without difficulty	283	22	38*	25	11	4
49. If there is any uncertainty that the catheter or wire resides in the vein, confirm venous residence of the wire after the wire is threaded; insertion of a dilator or large-bore catheter may then proceed	285	45	41*	8	5	1
50. After final catheterization and before use, confirm residence of the catheter in the venous system as soon as clinically appropriate	284	56*	36	6	1	1
51. Confirm the final position of the catheter tip as soon as clinically appropriate	283	59*	38	2	1	0
52. For central venous catheters placed in the operating room, perform a chest radiograph no later than the early postoperative period to confirm the position of the catheter tip	281	61*	34	4	1	0
53. Verify that the wire has not been retained in the vascular system at the end of the procedure by confirming the presence of the removed wire in the procedural field	284	68*	25	4	3	0
54. If the complete guidewire is not found in the procedural field, order chest radiography to determine whether the guidewire has been retained in the patient's vascular system	284	75*	22	2	1	0
Management of arterial trauma or injury arising from central venous catheterization						
55. When unintended cannulation of an arterial vessel with a dilator or large-bore catheter occurs, leave the dilator or catheter in place and immediately consult a general surgeon, a vascular surgeon, or an interventional radiologist regarding surgical or nonsurgical catheter removal for adults	279	56*	27	9	7	1
56. For neonates, infants, and children, determine on a case-by-case basis whether to leave the catheter in place and obtain consultation or to remove the catheter nonsurgically	276	26	32*	33	6	3
57. After the injury has been evaluated and a treatment plan has been executed, confer with the surgeon regarding relative risks and benefits of proceeding with the elective surgery <i>versus</i> deferring surgery to allow for a period of patient observation	278	50	45*	4	2	0

N = number of members who responded to each item.

*Median.

Acknowledgment

The authors thank David G. Nickinovich, Ph.D., Nickinovich Research and Consulting, Inc. (Bellevue, Washington) for his service as methodology consultant for this task force and his invaluable contributions to the original version of these Guidelines.

Research Support

Support was provided solely by the American Society of Anesthesiologists (Schaumburg, Illinois).

Competing Interests

The authors declare no competing interests.

Correspondence

Address correspondence to the American Society of Anesthesiologists: 1061 American Lane, Schaumburg, Illinois 60173. jeffa@dacc.uchicago.edu. These updated Practice Advisories, and all ASA Practice Parameters, may be obtained at no cost through the Journal Web site, www.anesthesiology.org.

References

1. American Society of Anesthesiologists Task Force on Central Venous A; Rupp SM, Apfelbaum JL, Blitt C, Caplan RA, Connis RT, Domino KB, Fleisher LA, Grant S, Mark JB, Morray JP, Nickinovich DG, Tung A: Practice guidelines for central venous access: A report by the American Society of Anesthesiologists Task Force on Central Venous Access. *ANESTHESIOLOGY* 2012; 116:539–73
2. Connis RT, Nickinovich DG, Caplan RA, Arens JF: The development of evidence-based clinical practice guidelines: Integrating medical science and practice. *Int J Technol Assess Health Care* 2000; 16:1003–12
3. Apfelbaum JL, Connis RT, Nickinovich DG: 2012 Emery A. Rovenstine Memorial Lecture: The genesis, development, and future of the American Society of Anesthesiologists evidence-based practice parameters. *ANESTHESIOLOGY* 2013; 118:767–8
4. Apfelbaum JL, Connis RT: The American Society of Anesthesiologists practice parameter methodology. *ANESTHESIOLOGY* 2019; 130:367–84
5. Connis RT, Nickinovich DG, Caplan RA, Apfelbaum JL: Evaluation and classification of evidence for the ASA clinical practice guidelines, Miller's Anesthesia, 8th edition. Edited by Miller RD. Philadelphia, Elsevier Saunders, 2015, pp 3257–70
6. Chua C, Wisniewski T, Ramos A, Schlepp M, Fildes JJ, Kuhls DA: Multidisciplinary trauma intensive care unit checklist: Impact on infection rates. *J Trauma Nurs* 2010; 17:163–6
7. Allen GB, Miller V, Nicholas C, Hess S, Cordes MK, Fortune JB, Blondin J, Ashikaga T, Ricci M: A multitiered strategy of simulation training, kit consolidation, and electronic documentation is associated with a reduction in central line-associated bloodstream infections. *Am J Infect Control* 2014; 42:643–8
8. Almeida CC, Pissarra da Silva SMS, Flor de Lima Caldas de Oliveira FSD, Guimarães Pereira Areias MHF: Nosocomial sepsis: Evaluation of the efficacy of preventive measures in a level-III neonatal intensive care unit. *J Matern Fetal Neonatal Med* 2017; 30:2036–41
9. Berenholtz SM, Pronovost PJ, Lipsett PA, Hobson D, Earsing K, Farley JE, Milanovich S, Garrett-Mayer E, Winters BD, Rubin HR, Dorman T, Perl TM: Eliminating catheter-related bloodstream infections in the intensive care unit. *Crit Care Med* 2004; 32:2014–20
10. Bion J, Richardson A, Hibbert P, Beer J, Abrusci T, McCutcheon M, Cassidy J, Eddleston J, Gunning K, Bellingan G, Patten M, Harrison D; Matching Michigan Collaboration & Writing Committee: "Matching Michigan": A 2-year stepped interventional programme to minimise central venous catheter-blood stream infections in intensive care units in England. *BMJ Qual Saf* 2013; 22:110–23
11. Burrell AR, McLaws ML, Murgo M, Calabria E, Pantle AC, Herkes R: Aseptic insertion of central venous lines to reduce bacteraemia: The central line associated bacteraemia in NSW intensive care units (CLAB ICU) collaborative. *Med J Australia* 2011; 194:583–7
12. Harris BD, Hanson C, Christy C, Adams T, Banks A, Willis TS, Maciejewski ML: Strict hand hygiene and other practices shortened stays and cut costs and mortality in a pediatric intensive care unit. *Health Aff (Millwood)* 2011; 30:1751–61
13. Higuera F, Rosenthal VD, Duarte P, Ruiz J, Franco G, Safdar N: The effect of process control on the incidence of central venous catheter-associated bloodstream infections and mortality in intensive care units in Mexico. *Crit Care Med* 2005; 33:2022–7
14. Hocking C, Pirret AM: Using a combined nursing and medical approach to reduce the incidence of central line associated bacteraemia in a New Zealand critical care unit: A clinical audit. *Intensive Crit Care Nurs* 2013; 29:137–46
15. Hsin HT, Hsu MS, Shieh JS: The long-term effect of bundle care for catheter-related blood stream infection: 5-year follow-up. *Postgrad Med J* 2017; 93:133–7
16. 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; 39:640–6

17. Klintworth G, Stafford J, O'Connor M, Leong T, Hamley L, Watson K, Kennon J, Bass P, Cheng AC, Worth LJ: Beyond the intensive care unit bundle: Implementation of a successful hospital-wide initiative to reduce central line-associated bloodstream infections. *Am J Infect Control* 2014; 42:685–7
18. Lin WP, Chang YC, Wu UI, Hung MC, Chuang PY, Wang JT, Sheng WH, Chen YC, Chang SC: Multimodal interventions for bundle implementation to decrease central line-associated bloodstream infections in adult intensive care units in a teaching hospital in Taiwan, 2009–2013. *J Microbiol Immunol Infect* 2018; 51:644–51
19. Longmate AG, Ellis KS, Boyle L, Maher S, Cairns CJ, Lloyd SM, Lang C: Elimination of central-venous-catheter-related bloodstream infections from the intensive care unit. *BMJ Qual Saf* 2011; 20:174–80
20. Martínez-Morel HR, Sanchez-Payá J, García-Shimizu P, Mendoza-García JL, Tenza-Iglesias I, Rodríguez-Díaz JC, Merino-DE-Lucas E, Nolasco A: Effectiveness of a programme to reduce the burden of catheter-related bloodstream infections in a tertiary hospital. *Epidemiol Infect* 2016; 144:2011–7
21. McLaws ML, Burrell AR: Zero risk for central line-associated bloodstream infection: Are we there yet? *Crit Care Med* 2012; 40:388–93
22. McMullan C, Propper G, Schuhmacher C, Sokoloff L, Harris D, Murphy P, Greene WH: A multidisciplinary approach to reduce central line-associated bloodstream infections. *Jt Comm J Qual Patient Saf* 2013; 39:61–9
23. Miller K, Briody C, Casey D, Kane JK, Mitchell D, Patel B, Ritter C, Seckel M, Wakai S, Drees M: Using the comprehensive unit-based safety program model for sustained reduction in hospital infections. *Am J Infect Control* 2016; 44:969–76
24. Miller MR, Griswold M, Harris JM 2nd, Yenokyan G, Huskins WC, Moss M, Rice TB, Ridling D, Campbell D, Margolis P, Muething S, Brill R: Decreasing PICU catheter-associated bloodstream infections: NACHRI's quality transformation efforts. *Pediatrics* 2010; 125:206–13
25. Miller MR, Niedner MF, Huskins WC, Colantuoni E, Yenokyan G, Moss M, Rice TB, Ridling D, Campbell D, Brill R: National Association of Children's Hospitals and Related Institutions Pediatric Intensive Care Unit Central Line-Associated Bloodstream Infection Quality Transformation Teams: Reducing PICU central line-associated bloodstream infections: 3-year results. *Pediatrics* 2011; 128:e1077–83
26. Munoz-Price LS, Dezfulian C, Wyckoff M, Lenchus JD, Rosalsky M, Birnbach DJ, Arheart KL: Effectiveness of stepwise interventions targeted to decrease central catheter-associated bloodstream infections. *Crit Care Med* 2012; 40:1464–9
27. Padilla Fortunatti CF: Impact of two bundles on central catheter-related bloodstream infection in critically ill patients. *Rev Lat Am Enfermagem* 2017; 25:e2951
28. Palomar M, Álvarez-Lerma F, Riera A, Díaz MT, Torres F, Agra Y, Larizgoitia I, Goeschel CA, Pronovost PJ; Bacteremia Zero Working Group: Impact of a national multimodal intervention to prevent catheter-related bloodstream infection in the ICU: The Spanish experience. *Crit Care Med* 2013; 41:2364–72
29. Pronovost P, Needham D, Berenholtz S, Sinopoli D, Chu H, Cosgrove S, Sexton B, Hyzy R, Welsh R, Roth G, Bander J, Kepros J, Goeschel C: An intervention to decrease catheter-related bloodstream infections in the ICU. *N Engl J Med* 2006; 355:2725–32
30. Reddy KK, Samuel A, Smiley KA, Weber S, Hon H: Reducing central line-associated bloodstream infections in three ICUs at a tertiary care hospital in the United Arab Emirates. *Jt Comm J Qual Patient Saf* 2014; 40:559–1
31. Render ML, Hasselbeck R, Freyberg RW, Hofer TP, Sales AE, Almenoff PL; VA ICU Clinical Advisory Group: Reduction of central line infections in Veterans Administration intensive care units: An observational cohort using a central infrastructure to support learning and improvement. *BMJ Qual Saf* 2011; 20:725–32
32. Richards GA, Brink AJ, Messina AP, Feldman C, Swart K, van den Bergh D; Netcare Antimicrobial Stewardship and Infection Prevention Study Alliance: Stepwise introduction of the “Best Care Always” central-line-associated bloodstream infection prevention bundle in a network of South African hospitals. *J Hosp Infect* 2017; 97:86–92
33. Rodríguez-Crèixems M, Muñoz P, Martín-Rabadán P, Cercenado E, Guembe M, Bouza E: Evolution and aetiological shift of catheter-related bloodstream infection in a whole institution: The microbiology department may act as a watchtower. *Clin Microbiol Infect* 2013; 19:845–51
34. Salama MF, Jamal WY, Mousa HA, Al-Abdulghani KA, Rotimi VO: The effect of hand hygiene compliance on hospital-acquired infections in an ICU setting in a Kuwaiti teaching hospital. *J Infect Public Health* 2013; 6:27–34
35. Schulman J, Stricof R, Stevens TP, Horgan M, Gase K, Holzman IR, Koppel RI, Nafday S, Gibbs K, Angert R, Simmonds A, Furdon SA, Saiman L; New York State Regional Perinatal Care Centers: Statewide NICU central-line-associated bloodstream infection rates decline after bundles and checklists. *Pediatrics* 2011; 127:436–44
36. Shepherd EG, Kelly TJ, Vinsel JA, Cunningham DJ, Keels E, Beauseau W, McClead RE Jr: Significant reduction of central-line associated bloodstream infections in a network of diverse neonatal nurseries. *J Pediatr* 2015; 167:41–6.e1–3
37. Al-Tawfiq JA, Amalraj A, Memish ZA: Reduction and surveillance of device-associated infections in adult intensive care units at a Saudi Arabian hospital, 2004–2011. *Int J Infect Dis* 2013; 17:e1207–11

38. Balla KC, Rao SP, Arul C, Shashidhar A, Prashantha YN, Nagaraj S, Suresh G: Decreasing central line-associated bloodstream infections through quality improvement initiative. *Indian Pediatr* 2018; 55:753–6
39. Dumyati G, Concannon C, van Wijngaarden E, Love TM, Graman P, Pettis AM, Greene L, El-Daher N, Farnsworth D, Quinlan G, Karr G, Ward L, Knab R, Shelly M: Sustained reduction of central line-associated bloodstream infections outside the intensive care unit with a multimodal intervention focusing on central line maintenance. *Am J Infect Control* 2014; 42:723–30
40. Esteban E, Ferrer R, Urrea M, Suarez D, Rozas L, Balaguer M, Palomeque A, Jordan I: The impact of a quality improvement intervention to reduce nosocomial infections in a PICU. *Pediatr Crit Care Med* 2013; 14:525–32
41. Exline MC, Ali NA, Zikri N, Mangino JE, Torrence K, Vermillion B, St Clair J, Lustberg ME, Pancholi P, Sopirala MM: Beyond the bundle: Journey of a tertiary care medical intensive care unit to zero central line-associated bloodstream infections. *Crit Care* 2013; 17:R41
42. Hong AL, Sawyer MD, Shore A, Winters BD, Masuga M, Lee H, Mathews SC, Weeks K, Goeschel CA, Berenholtz SM, Pronovost PJ, Lubomski LH: On the CUSP: Stop BSI Program: Decreasing central-line-associated bloodstream infections in Connecticut intensive care units. *J Healthc Qual* 2013; 35:78–87
43. Jeong IS, Park SM, Lee JM, Song JY, Lee SJ: Effect of central line bundle on central line-associated bloodstream infections in intensive care units. *Am J Infect Control* 2013; 41:710–6
44. Kellie SP, Scott MJ, Cavallazzi R, Wiemken TL, Goss L, Parker D, Saad M: Procedural and educational interventions to reduce ventilator-associated pneumonia rate and central line-associated blood stream infection rate. *J Intensive Care Med* 2014; 29:165–74
45. Mazi W, Begum Z, Abdulla D, Hesham A, Maghari S, Assiri A, Senok A: Central line-associated bloodstream infection in a trauma intensive care unit: Impact of implementation of Society for Healthcare Epidemiology of America/Infectious Diseases Society of America practice guidelines. *Am J Infect Control* 2014; 42:865–7
46. Mueller JT, Wright AJ, Fedraw LA, Murad MH, Brown DR, Thompson KM, Flick R, Seville MT, Huskins WC: Standardizing central line safety: Lessons learned for physician leaders. *Am J Med Qual* 2014; 29:191–9
47. Pageler NM, Longhurst CA, Wood M, Cornfield DN, Suermondt J, Sharek PJ, Franzon D: Use of electronic medical record-enhanced checklist and electronic dashboard to decrease CLABSIs. *Pediatrics* 2014; 133:e738–46
48. Park SW, Ko S, An HS, Bang JH, Chung WY: Implementation of central line-associated bloodstream infection prevention bundles in a surgical intensive care unit using peer tutoring. *Antimicrob Resist Infect Control* 2017; 6:103
49. Paula AP, Oliveira PR, Miranda EP, Felix CS, Lorigados CB, Giovani AM, Lima AL: The long-term impact of a program to prevent central line-associated bloodstream infections in a surgical intensive care unit. *Clinics (Sao Paulo)* 2012; 67:969–70
50. Remington L, Faraklas I, Gauthier K, Carper C, Wiggins JB, Lewis GM, Cochran A: Assessment of a central line-associated bloodstream infection prevention program in a burn-trauma intensive care unit. *JAMA Surg* 2016; 151:485–6
51. Sacks GD, Diggs BS, Hadjizacharia P, Green D, Salim A, Malinoski DJ: Reducing the rate of catheter-associated bloodstream infections in a surgical intensive care unit using the Institute for Healthcare Improvement Central Line Bundle. *Am J Surg* 2014; 207:817–23
52. Salama MF, Jamal W, Al Mousa H, Rotimi V: Implementation of central venous catheter bundle in an intensive care unit in Kuwait: Effect on central line-associated bloodstream infections. *J Infect Public Health* 2016; 9:34–41
53. 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
54. Warren DK, Cosgrove SE, Diekema DJ, Zuccotti G, Climo MW, Bolon MK, Tokars JI, Noskin GA, Wong ES, Sepkowitz KA, Herwaldt LA, Perl TM, Solomon SL, Fraser VJ: Prevention Epicenter Program: A multicenter intervention to prevent catheter-associated bloodstream infections. *Infect Control Hosp Epidemiol* 2006; 27:662–9
55. Wu PP, Liu CE, Chang CY, Huang HC, Syu SS, Wang CH, Huang YC: Decreasing catheter-related bloodstream infections in the intensive care unit: Interventions in a medical center in central Taiwan. *J Microbiol Immunol Infect* 2012; 45:370–6
56. Ahmed SS, McCaskey MS, Bringman S, Eigen H: Catheter-associated bloodstream infection in the pediatric intensive care unit: A multidisciplinary approach. *Pediatr Crit Care Med* 2012; 13:e69–72
57. Berenholtz SM, Lubomski LH, Weeks K, Goeschel CA, Marsteller JA, Pham JC, Sawyer MD, Thompson DA, Winters BD, Cosgrove SE, Yang T, Louis TA, Meyer Lucas B, George CT, Watson SR, Albert-Leshner MI, St Andre JR, Combes JR, Bohr D, Hines SC, Battles JB, Pronovost PJ: On the CUSP: Stop BSI program: Eliminating central line-associated bloodstream infections: A national patient safety imperative. *Infect Control Hosp Epidemiol* 2014; 35:56–62
58. Ceballos K, Waterman K, Hulett T, Makic MB: Nurse-driven quality improvement interventions to reduce hospital-acquired infection in the NICU. *Adv Neonatal Care* 2013; 13:154–63

59. 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; 355:1864–8
60. Gray J, Proudfoot S, Power M, Bennett B, Wells S, Seddon M: Target CLAB Zero: A national improvement collaborative to reduce central line-associated bacteraemia in New Zealand intensive care units. *N Z Med J* 2015; 128:13–21
61. Hansen S, Schwab F, Schneider S, Sohr D, Gastmeier P, Geffers C: Time-series analysis to observe the impact of a centrally organized educational intervention on the prevention of central-line-associated bloodstream infections in 32 German intensive care units. *J Hosp Infect* 2014; 87:220–6
62. Henderson DM, Staiger TO, Peterson GN, Sinanan MN, Angiulo CL, Makarewicz VA, Wild LM, Whimbey EE: A collaborative, systems-level approach to eliminating healthcare-associated MRSA, central-line-associated bloodstream infections, ventilator-associated pneumonia, and respiratory virus infections. *J Healthc Qual* 2012; 34:39–47
63. Kuo SH, Lin WR, Lin JY, Huang CH, Jao YT, Yang PW, Tsai JR, Wang WH, Chen YH, Hung CT, Lu PL: The epidemiology, antibiograms and predictors of mortality among critically-ill patients with central line-associated bloodstream infections. *J Microbiol Immunol Infect* 2018; 51:401–10
64. Latif A, Kelly B, Edrees H, Kent PS, Weaver SJ, Jovanovic B, Attallah H, de Grouchy KK, Al-Obaidli A, Goeschel CA, Berenholtz SM: Implementing a multifaceted intervention to decrease central line-associated bloodstream infections in SEHA (Abu Dhabi Health Services Company) intensive care units: The Abu Dhabi experience. *Infect Control Hosp Epidemiol* 2015; 36:816–22
65. Lin DM, Weeks K, Bauer L, Combes JR, George CT, Goeschel CA, Lubomski LH, Mathews SC, Sawyer MD, Thompson DA, Watson SR, Winters BD, Marsteller JA, Berenholtz SM, Pronovost PJ, Pham JC: Eradicating central line-associated bloodstream infections statewide: The Hawaii experience. *Am J Med Qual* 2012; 27:124–9
66. Lin DM, Weeks K, Holzmüller CG, Pronovost PJ, Pham JC: Maintaining and sustaining the On the CUSP: Stop BSI model in Hawaii. *Jt Comm J Qual Patient Saf* 2013; 39:51–60
67. Seddon ME, Hocking CJ, Bryce EA, Hillman J, McCoubrie V: From ICU to hospital-wide: Extending central line associated bacteraemia (CLAB) prevention. *N Z Med J* 2014; 127:60–71
68. Seddon ME, Hocking CJ, Mead P, Simpson C: Aiming for zero: Decreasing central line associated bacteraemia in the intensive care unit. *N Z Med J* 2011; 124:9–21
69. Southworth SL, Henman LJ, Kinder LA, Sell JL: The journey to zero central catheter-associated bloodstream infections: Culture change in an intensive care unit. *Crit Care Nurse* 2012; 32:49–54
70. Wallace MC, Macy DL: Reduction of central line-associated bloodstream infection rates in patients in the adult intensive care unit. *J Infus Nurs* 2016; 39:47–55
71. Zingg W, Cartier V, Inan C, Touveneau S, Theriault M, Gayet-Ageron A, Clergue F, Pittet D, Walder B: Hospital-wide multidisciplinary, multimodal intervention programme to reduce central venous catheter-associated bloodstream infection. *PLoS One* 2014; 9:e93898
72. Raad II, Hohn DC, Gilbreath BJ, Suleiman N, Hill LA, Bruso PA, Marts K, Mansfield PF, Bodey GP: Prevention of central venous catheter-related infections by using maximal sterile barrier precautions during insertion. *Infect Control Hosp Epidemiol* 1994; 15:231–8
73. Maki DG, Ringer M, Alvarado CJ: Prospective randomised trial of povidone-iodine, alcohol, and chlorhexidine for prevention of infection associated with central venous and arterial catheters. *Lancet* 1991; 338:339–43
74. Mimoz O, Lucet JC, Kerforne T, Pascal J, Souweine B, Goudet V, Mercat A, Bouadma L, Lasocki S, Alfandari S, Friggeri A, Wallet F, Allou N, Ruckly S, Balayn D, Lepape A, Timsit JF; CLEAN trial investigators: 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; 386:2069–77
75. Yasuda H, Sanui M, Abe T, Shime N, Komuro T, Hatakeyama J, Matsukubo S, Kawano S, Yamamoto H, Andoh K, Seo R, Inoue K, Noda E, Saito N, Nogami S, Okamoto K, Fuke R, Gushima Y, Kobayashi A, Takebayashi T, Lefor AK; for Japanese Society of Education for Physicians and Trainees in Intensive Care (JSEPTIC) Clinical Trial Group: 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
76. Pages J, Hazera P, Mégarbane B, du Cheyron D, Thuong M, Dutheil JJ, Valette X, Fournel F, Mermel LA, Mira JP, Daubin C, Parienti JJ; 3SITES Study Group: 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; 42:1418–26
77. Parienti JJ, du Cheyron D, Ramakers M, Malbrun B, Leclercq R, Le Coutour X, Charbonneau P; Members of the NACRE Study Group: Alcoholic povidone-iodine to prevent central venous catheter colonization: A randomized unit-crossover study. *Crit Care Med* 2004; 32:708–13
78. Bach A, Darby D, Böttiger B, Böhler H, Motsch J, Martin E: Retention of the antibiotic teicoplanin on a hydromer-coated central venous catheter to prevent

- bacterial colonization in postoperative surgical patients. *Intensive Care Med* 1996; 22:1066–9
79. Kamal GD, Pfaller MA, Rempe LE, Jebson PJ: Reduced intravascular catheter infection by antibiotic bonding: A prospective, randomized, controlled trial. *JAMA* 1991; 265:2364–8
 80. León C, Ruiz-Santana S, Rello J, de la Torre MV, Vallés J, Alvarez-Lerma F, Sierra R, Saavedra P, Alvarez-Salgado F; Cabaña Study Group: Benefits of minocycline and rifampin-impregnated central venous catheters: A prospective, randomized, double-blind, controlled, multicenter trial. *Intensive Care Med* 2004; 30:1891–9
 81. Raad I, Darouiche R, Dupuis J, Abi-Said D, Gabrielli A, Hachem R, Wall M, Harris R, Jones J, Buzaid A, Robertson C, Shenag S, Curling P, Burke T, Ericsson C: 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; 127:267–74
 82. Thornton J, Todd NJ, Webster NR: Central venous line sepsis in the intensive care unit: A study comparing antibiotic coated catheters with plain catheters. *Anaesthesia* 1996; 51:1018–20
 83. Marik PE, Abraham G, Careau P, Varon J, Fromm RE Jr: The *ex vivo* antimicrobial activity and colonization rate of two antimicrobial-bonded central venous catheters. *Crit Care Med* 1999; 27:1128–31
 84. Raad II, Darouiche RO, Hachem R, Abi-Said D, Safar H, Darnule T, Mansouri M, Morck D: Antimicrobial durability and rare ultrastructural colonization of indwelling central catheters coated with minocycline and rifampin. *Crit Care Med* 1998; 26:219–24
 85. Yücel N, Lefering R, Maegele M, Max M, Rossaint R, Koch A, Schwarz R, Korenkov M, Beuth J, Bach A, Schierholz J, Pulverer G, Neugebauer EA: Reduced colonization and infection with miconazole-rifampicin modified central venous catheters: A randomized controlled clinical trial. *J Antimicrob Chemother* 2004; 54:1109–15
 86. Gilbert RE, Mok Q, Dwan K, Harron K, Moitt T, Millar M, Ramnarayan P, Tibby SM, Hughes D, Gamble C; CATCH trial investigators: Impregnated central venous catheters for prevention of bloodstream infection in children (the CATCH trial): A randomised controlled trial. *Lancet* 2016; 387:1732–42
 87. Bong JJ, Kite P, Wilco MH, McMahon MJ: Prevention of catheter related bloodstream infection by silver iontophoretic central venous catheters: A randomised controlled trial. *J Clin Pathol* 2003; 56:731–5
 88. Böswald M, Lugauer S, Regenfus A, Braun GG, Martus P, Geis C, Scharf J, Bechert T, Greil J, Guggenbichler JP: Reduced rates of catheter-associated infection by use of a new silver-impregnated central venous catheter. *Infection* 1999; 27:S56–60
 89. Kalfon P, de Vaumas C, Samba D, Boulet E, Lefrant JY, Eyraud D, Lherm T, Santoli F, Naija W, Riou B: Comparison of silver-impregnated with standard multi-lumen central venous catheters in critically ill patients. *Crit Care Med* 2007; 35:1032–9
 90. Arvaniti K, Lathyris D, Clouva-Molyvdas P, Haidich AB, Mouloudi E, Synnefaki E, Koulourida V, Georgopoulos D, Gerogianni N, Nakos G, Matamis D; Catheter-Related Infections in ICU (CRI-ICU) Group: Comparison of Oligon catheters and chlorhexidine-impregnated sponges with standard multi-lumen central venous catheters for prevention of associated colonization and infections in intensive care unit patients: A multicenter, randomized, controlled study. *Crit Care Med* 2012; 40:420–9
 91. Antonelli M, De Pascale G, Ranieri VM, Pelaia P, Tufano R, Piazza O, Zangrillo A, Ferrario A, De Gaetano A, Guaglianone E, Donelli G: Comparison of triple-lumen central venous catheters impregnated with silver nanoparticles (AgTive®) vs. conventional catheters in intensive care unit patients. *J Hosp Infect* 2012; 82:101–7
 92. Moretti EW, Ofstead CL, Kristy RM, Wetzler HP: Impact of central venous catheter type and methods on catheter-related colonization and bacteraemia. *J Hosp Infect* 2005; 61:139–45
 93. Bach A, Eberhardt H, Frick A, Schmidt H, Böttiger BW, Martin E: Efficacy of silver-coating central venous catheters in reducing bacterial colonization. *Crit Care Med* 1999; 27:515–21
 94. Corral L, Nolla-Salas M, Ibañez-Nolla J, León MA, Díaz RM, Cruz Martín M, Iglesia R, Catalan R: A prospective, randomized study in critically ill patients using the Oligon Vantex catheter. *J Hosp Infect* 2003; 55:212–9
 95. Dünser MW, Mayr AJ, Hinterberger G, Flörl CL, Ulmer H, Schmid S, Friesenecker B, Lorenz I, Hasibeder WR: Central venous catheter colonization in critically ill patients: A prospective, randomized, controlled study comparing standard with two antiseptic-impregnated catheters. *Anesth Analg* 2005; 101:1778–84
 96. Goldschmidt H, Hahn U, Salvender HJ, Haas R, Jansen B, Wolbring P, Rinck M, Hunstein W: Prevention of catheter-related infections by silver coated central venous catheters in oncological patients. *Zentralbl Bakteriol* 1995; 283:215–23
 97. Stoiser B, Kofler J, Staudinger T, Georgopoulos A, Lugauer S, Guggenbichler JP, Burgmann H, Frass M: Contamination of central venous catheters in immunocompromised patients: A comparison between two different types of central venous catheters. *J Hosp Infect* 2002; 50:202–6
 98. Hagau N, Studniska D, Gavrus RL, Csipak G, Hagau R, Slavcovici AV: Central venous catheter colonization and catheter-related bloodstream infections in

- critically ill patients: A comparison between standard and silver-integrated catheters. *Eur J Anaesthesiol* 2009; 26:752–8
99. Harter C, Salwender HJ, Bach A, Egerer G, Goldschmidt H, Ho AD: Catheter-related infection and thrombosis of the internal jugular vein in hematologic-oncologic patients undergoing chemotherapy: A prospective comparison of silver-coated and uncoated catheters. *Cancer* 2002; 94:245–51
 100. Bach A, Schmidt H, Böttiger B, Schreiber B, Böhler H, Motsch J, Martin E, Sonntag HG: Retention of antibacterial activity and bacterial colonization of antiseptic-bonded central venous catheters. *J Antimicrob Chemother* 1996; 37:315–22
 101. Brun-Buisson C, Doyon F, Sollet JP, Cochard JE, Cohen Y, Nitenberg G: Prevention of intravascular catheter-related infection with newer chlorhexidine-silver sulfadiazine-coated catheters: A randomized controlled trial. *Intensive Care Med* 2004; 30:837–43
 102. Ciresi DL, Albrecht RM, Volkers PA, Scholten DJ: Failure of antiseptic bonding to prevent central venous catheter-related infection and sepsis. *Am Surg* 1996; 62:641–6
 103. Collin GR: Decreasing catheter colonization through the use of an antiseptic-impregnated catheter: A continuous quality improvement project. *Chest* 1999; 115:1632–40
 104. George SJ, Vuddamalai P, Boscoe MJ: Antiseptic-impregnated central venous catheters reduce the incidence of bacterial colonization and associated infection in immunocompromised transplant patients. *Eur J Anaesthesiol* 1997; 14:428–31
 105. Hannan M, Juste RN, Umasanker S, Glendenning A, Nightingale C, Azadian B, Soni N: Antiseptic-bonded central venous catheters and bacterial colonisation. *Anaesthesia* 1999; 54:868–72
 106. Heard SO, Wagle M, Vijayakumar E, McLean S, Brueggemann A, Napolitano LM, Edwards LP, O'Connell FM, Puyana JC, Doern GV: Influence of triple-lumen central venous catheters coated with chlorhexidine and silver sulfadiazine on the incidence of catheter-related bacteremia. *Arch Intern Med* 1998; 158:81–7
 107. Maki DG, Stolz SM, Wheeler S, Mermel LA: Prevention of central venous catheter-related bloodstream infection by use of an antiseptic-impregnated catheter: A randomized, controlled trial. *Ann Intern Med* 1997; 127:257–66
 108. Ostendorf T, Meinhold A, Harter C, Salwender H, Egerer G, Geiss HK, Ho AD, Goldschmidt H: Chlorhexidine and silver-sulfadiazine coated central venous catheters in haematological patients: A double-blind, randomised, prospective, controlled trial. *Support Care Cancer* 2005; 13:993–1000
 109. Rupp ME, Lisco SJ, Lipsett PA, Perl TM, Keating K, Civetta JM, Mermel LA, Lee D, Dellinger EP, Donahoe M, Giles D, Pfaller MA, Maki DG, Sherertz R: Effect of a second-generation venous catheter impregnated with chlorhexidine and silver sulfadiazine on central catheter-related infections: A randomized, controlled trial. *Ann Intern Med* 2005; 143:570–80
 110. Tennenberg S, Lieser M, McCurdy B, Boomer G, Howington E, Newman C, Wolf I: A prospective randomized trial of an antibiotic- and antiseptic-coated central venous catheter in the prevention of catheter-related infections. *Arch Surg* 1997; 132:1348–51
 111. van Heerden PV, Webb SA, Fong S, Golledge CL, Roberts BL, Thompson WR: Central venous catheters revisited: Infection rates and an assessment of the new fibrin analysing system brush. *Anaesth Intensive Care* 1996; 24:330–3
 112. Camargo LF, Marra AR, Büchele GL, Sogayar AM, Cal RG, de Sousa JM, Silva E, Knobel E, Edmond MB: Double-lumen central venous catheters impregnated with chlorhexidine and silver sulfadiazine to prevent catheter colonisation in the intensive care unit setting: A prospective randomised study. *J Hosp Infect* 2009; 72:227–33
 113. Jaeger K, Zenz S, Jüttner B, Ruschulte H, Kuse E, Heine J, Piepenbrock S, Ganser A, Karthaus M: Reduction of catheter-related infections in neutropenic patients: A prospective controlled randomized trial using a chlorhexidine and silver sulfadiazine-impregnated central venous catheter. *Ann Hematol* 2005; 84:258–62
 114. Mer M, Duse AG, Galpin JS, Richards GA: Central venous catheterization: A prospective, randomized, double-blind study. *Clin Appl Thromb Hemost* 2009; 15:19–26
 115. Osma S, Kahveci SF, Kaya FN, Akalin H, Ozakin C, Yilmaz E, Kutlay O: Efficacy of antiseptic-impregnated catheters on catheter colonization and catheter-related bloodstream infections in patients in an intensive care unit. *J Hosp Infect* 2006; 62:156–62
 116. Sheng WH, Ko WJ, Wang JT, Chang SC, Hsueh PR, Luh KT: Evaluation of antiseptic-impregnated central venous catheters for prevention of catheter-related infection in intensive care unit patients. *Diagn Microbiol Infect Dis* 2000; 38:1–5
 117. Theaker C, Juste R, Lucas N, Tallboys C, Azadian B, Soni N: Comparison of bacterial colonization rates of antiseptic impregnated and pure polymer central venous catheters in the critically ill. *J Hosp Infect* 2002; 52:310–2
 118. van Vliet J, Leusink JA, de Jongh BM, de Boer A: A comparison between two types of central venous catheters in the prevention of catheter-related infections: The importance of performing all the relevant cultures. *Clinical Intensive Care* 2001; 12:135–40

119. Logghe C, Van Ossel C, D'Hoore W, Ezzedine H, Wauters G, Haxhe JJ: Evaluation of chlorhexidine and silver-sulfadiazine impregnated central venous catheters for the prevention of bloodstream infection in leukaemic patients: A randomized controlled trial. *J Hosp Infect* 1997; 37:145–56
120. Pemberton LB, Ross V, Cuddy P, Kremer H, Fessler T, McGurk E: No difference in catheter sepsis between standard and antiseptic central venous catheters: A prospective randomized trial. *Arch Surg* 1996; 131:986–9
121. Oda T, Hamasaki J, Kanda N, Mikami K: Anaphylactic shock induced by an antiseptic-coated central venous [correction of nervous] catheter. *ANESTHESIOLOGY* 1997; 87:1242–4
122. Stephens R, Mythen M, Kallis P, Davies DW, Egner W, Rickards A: Two episodes of life-threatening anaphylaxis in the same patient to a chlorhexidine-sulphadiazine-coated central venous catheter. *Br J Anaesth* 2001; 87:306–8
123. Terazawa E, Shimonaka H, Nagase K, Masue T, Dohi S: Severe anaphylactic reaction due to a chlorhexidine-impregnated central venous catheter. *ANESTHESIOLOGY* 1998; 89:1296–8
124. Faber M, Leysen J, Bridts C, Sabato V, De Clerck LS, Ebo DG: Allergy to chlorhexidine: Beware of the central venous catheter. *Acta Anaesthesiol Belg* 2012; 63:191–4
125. 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; 13:171–4
126. Khoo A, Oziemski P: Chlorhexidine impregnated central venous catheter inducing an anaphylactic shock in the intensive care unit. *Heart Lung Circ* 2011; 20:669–70
127. Qin Z, Zeng Z: Anaphylaxis to chlorhexidine in a chlorhexidine-coated central venous catheter during general anaesthesia. *Anaesth Intensive Care* 2016; 44:297–8
128. Toomey M: Preoperative chlorhexidine anaphylaxis in a patient scheduled for coronary artery bypass graft: A case report. *AANA J* 2013; 81:209–14
129. Wang ML, Chang CT, Huang HH, Yeh YC, Lee TS, Hung KY: Chlorhexidine-related refractory anaphylactic shock: A case successfully resuscitated with extracorporeal membrane oxygenation. *J Clin Anesth* 2016; 34:654–7
130. Merrer J, De Jonghe B, Golliot F, Lefrant JY, Raffy B, Barre E, Rigaud JP, Casciani D, Misset B, Bosquet C, Outin H, Brun-Buisson C, Nitenberg G; French Catheter Study Group in Intensive Care: Complications of femoral and subclavian venous catheterization in critically ill patients: A randomized controlled trial. *JAMA* 2001; 286:700–7
131. Parienti JJ, Mongardon N, Mégarbane B, Mira JP, Kalfon P, Gros A, Marqué S, Thuong M, Pottier V, Ramakers M, Savary B, Seguin A, Valette X, Terzi N, Sauneuf B, Cattoir V, Mermel LA, du Cheyron D; 3SITES Study Group: Intravascular complications of central venous catheterization by insertion site. *N Engl J Med* 2015; 373:1220–9
132. Ramos GE, Bolgiani AN, Patiño O, Prezzavento GE, Guastavino P, Durlach R, Fernandez Canigia LB, Benaim F: Catheter infection risk related to the distance between insertion site and burned area. *J Burn Care Rehabil* 2002; 23:266–71
133. Garland JS, Alex CP, Mueller CD, Otten D, Shivpuri C, Harris MC, Naples M, Pellegrini J, Buck RK, McAuliffe TL, Goldmann DA, Maki DG: A randomized trial comparing povidone-iodine to a chlorhexidine gluconate-impregnated dressing for prevention of central venous catheter infections in neonates. *Pediatrics* 2001; 107:1431–6
134. Levy I, Katz J, Solter E, Samra Z, Vidne B, Birk E, Ashkenazi S, Dagan O: Chlorhexidine-impregnated dressing for prevention of colonization of central venous catheters in infants and children: A randomized controlled study. *Pediatr Infect Dis J* 2005; 24:676–9
135. Roberts B, Cheung D: Biopatch: A new concept in antimicrobial dressings for invasive devices. *Aust Crit Care* 1998; 11:16–9
136. Timsit JF, Schwebel C, Bouadma L, Geffroy A, Garrouste-Orgeas M, Pease S, Herault MC, Haouache H, Calvino-Gunther S, Gestin B, Armand-Lefevre L, Leflon V, Chaplain C, Benali A, Francois A, Adrie C, Zahar JR, Thuong M, Arrault X, Croize J, Lucet JC; Dressing Study Group: Chlorhexidine-impregnated sponges and less frequent dressing changes for prevention of catheter-related infections in critically ill adults: A randomized controlled trial. *JAMA* 2009; 301:1231–41
137. Timsit JF, Mimoz O, Mourvillier B, Souweine B, Garrouste-Orgeas M, Alfandari S, Plantefeve G, Bronchard R, Troche G, Gauzit R, Antona M, Canet E, Bohe J, Lepape A, Vesin A, Arrault X, Schwebel C, Adrie C, Zahar JR, Ruckly S, Tournegros C, Lucet JC: 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; 186:1272–8
138. Düzkaya DS, Sahiner NC, Uysal G, Yakut T, Çitak A: Chlorhexidine-impregnated dressings and prevention of catheter-associated bloodstream infections in a pediatric intensive care unit. *Crit Care Nurse* 2016; 36:e1–7
139. Biehl LM, Huth A, Panse J, Krämer C, Hentrich M, Engelhardt M, Schäfer-Eckart K, Kofla G, Kiehl M, Wendtner CM, Karthaus M, Ullmann AJ, Hellmich

- M, Christ H, Vehreschild MJ: A randomized trial on chlorhexidine dressings for the prevention of catheter-related bloodstream infections in neutropenic patients. *Ann Oncol* 2016; 27:1916–22
140. Ruschulte H, Franke M, Gastmeier P, Zenz S, Mahr KH, Buchholz S, Hertenstein B, Hecker H, Piepenbrock S: Prevention of central venous catheter related infections with chlorhexidine gluconate impregnated wound dressings: A randomized controlled trial. *Ann Hematol* 2009; 88:267–72
 141. Pedrolo E, Danski MT, Vayego SA: Chlorhexidine and gauze and tape dressings for central venous catheters: A randomized clinical trial. *Rev Lat Am Enfermagem* 2014; 22:764–71
 142. Gil RT, Kruse JA, Thill-Baharozian MC, Carlson RW: Triple- vs. single-lumen central venous catheters: A prospective study in a critically ill population. *Arch Intern Med* 1989; 149:1139–43
 143. Moro ML, Viganò EF, Cozzi Lepri A: Risk factors for central venous catheter-related infections in surgical and intensive care units. The Central Venous Catheter-Related Infections Study Group. *Infect Control Hosp Epidemiol* 1994; 15:253–64
 144. Bicudo D, Batista R, Furtado GH, Sola A, Medeiros EA: Risk factors for catheter-related bloodstream infection: A prospective multicenter study in Brazilian intensive care units. *Braz J Infect Dis* 2011; 15:328–31
 145. Timsit JF, L'Hériveau F, Lepape A, Francois A, Ruckly S, Venier AG, Jarno P, Boussat S, Coignard B, Savey A: A multicentre analysis of catheter-related infection based on a hierarchical model. *Intensive Care Med* 2012; 38:1662–72
 146. Bonawitz SC, Hammell EJ, Kirkpatrick JR: Prevention of central venous catheter sepsis: A prospective randomized trial. *Am Surg* 1991; 57:618–23
 147. Kowalewska-Grochowska K, Richards R, Moysa GL, Lam K, Costerton JW, King EG: Guidewire catheter change in central venous catheter biofilm formation in a burn population. *Chest* 1991; 100:1090–5
 148. Snyder RH, Archer FJ, Endy T, Allen TW, Condon B, Kaiser J, Whatmore D, Harrington G, McDermott CJ: Catheter infection: A comparison of two catheter maintenance techniques. *Ann Surg* 1988; 208:651–3
 149. Michel LA, Bradpiece HA, Randour P, Pouthier F: Safety of central venous catheter change over guidewire for suspected catheter-related sepsis: A prospective randomized trial. *Int Surg* 1988; 73:180–6
 150. Kealey GP, Chang P, Heinle J, Rosenquist MD, Lewis RW 2nd: Prospective comparison of two management strategies of central venous catheters in burn patients. *J Trauma* 1995; 38:344–9
 151. Lucet JC, Hayon J, Bruneel F, Dumoulin JL, Joly-Guillou ML: Microbiological evaluation of central venous catheter administration hubs. *Infect Control Hosp Epidemiol* 2000; 21:40–2
 152. Casey AL, Burnell S, Whinn H, Worthington T, Faroqui MH, Elliott TS: A prospective clinical trial to evaluate the microbial barrier of a needleless connector. *J Hosp Infect* 2007; 65:212–8
 153. 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; 54:288–93
 154. Yébenes JC, Vidaur L, Serra-Prat M, Sirvent JM, Batlle J, Motje M, Bonet A, Palomar M: Prevention of catheter-related bloodstream infection in critically ill patients using a disinfectable, needle-free connector: A randomized controlled trial. *Am J Infect Control* 2004; 32:291–5
 155. Kaiser CW, Koornick AR, Smith N, Soroff HS: Choice of route for central venous cannulation: Subclavian or internal jugular vein? A prospective randomized study. *J Surg Oncol* 1981; 17:345–54
 156. Kocum A, Sener M, Caliskan E, Bozdogan N, Atalay H, Aribogan A: An alternative central venous route for cardiac surgery: Supraclavicular subclavian vein catheterization. *J Cardiothorac Vasc Anesth* 2011; 25:1018–23
 157. Karaaslan P, Gokay BV, Karakaya MA, Darcin K, Karakaya AD, Ormeci T, Kose EA: Comparison of the Trendelenburg position versus upper-limb tourniquet on internal jugular vein diameter. *Ann Saudi Med* 2017; 37:308–12
 158. Suarez T, Baerwald JP, Kraus C: Central venous access: The effects of approach, position, and head rotation on internal jugular vein cross-sectional area. *Anesth Analg* 2002; 95:1519–24
 159. Parry G: Trendelenburg position, head elevation and a midline position optimize right internal jugular vein diameter. *Can J Anaesth* 2004; 51:379–81
 160. Bellazzini MA, Rankin PM, Gangnon RE, Bjoernsen LP: Ultrasound validation of maneuvers to increase internal jugular vein cross-sectional area and decrease compressibility. *Am J Emerg Med* 2009; 27:454–9
 161. Armstrong PJ, Sutherland R, Scott DH: The effect of position and different manoeuvres on internal jugular vein diameter size. *Acta Anaesthesiol Scand* 1994; 38:229–31
 162. Samy Modeliar S, Sevestre MA, de Cagny B, Slama M: Ultrasound evaluation of central veins in the intensive care unit: Effects of dynamic manoeuvres. *Intensive Care Med* 2008; 34:333–8
 163. Nassar B, Deol GRS, Ashby A, Collett N, Schmidt GA: Trendelenburg position does not increase cross-sectional area of the internal jugular vein predictably. *Chest* 2013; 144:177–82
 164. Gok F, Sarkilar G, Kilicaslan A, Yosunkaya A, Uzun ST: Comparison of the effect of the Trendelenburg and passive leg raising positions on internal jugular vein

- size in critically ill patients. *Int J Clin Exp Med* 2015; 8:19037–43
165. Sayin MM, Mercan A, Koner O, Ture H, Celebi S, Sozubir S, Aykac B: Internal jugular vein diameter in pediatric patients: Are the J-shaped guidewire diameters bigger than internal jugular vein? An evaluation with ultrasound. *Paediatr Anaesth* 2008; 18:745–51
 166. Kim HY, Choi JM, Lee YH, Lee S, Yoo H, Gwak M: Effects of the Trendelenburg position and positive end-expiratory pressure on the internal jugular vein cross-sectional area in children with simple congenital heart defects. *Medicine (Baltimore)* 2016; 95:e3525
 167. Dinciyurek GN, Mogol EB, Turker G, Yavascaoglu B, Gurbet A, Kaya FN, Moustafa BR, Yazici T: The effects of the Trendelenburg position and the Valsalva manoeuvre on internal jugular vein diameter and placement in children. *Singapore Med J* 2015; 56:468–71
 168. Karaaslan P, Darcin K, Ormeci T, Karakaya MA, Ince A, Aslan NA, Tastekin A: Effects of varying entry points and trendelenburg positioning degrees in internal jugular vein area measurements of newborns. *Niger J Clin Pract* 2018; 21:514–8
 169. Brown CQ: Inadvertent prolonged cannulation of the carotid artery. *Anesth Analg* 1982; 61:150–2
 170. Digby S: Fatal respiratory obstruction following insertion of a central venous line. *Anaesthesia* 1994; 49:1013–4
 171. Farhat K, Nakhjavan K, Cope C, Yazdanfar S, Fernandez J, Gooch A, Goldberg H: Iatrogenic arteriovenous fistula: A complication of percutaneous subclavian vein puncture. *Chest* 1975; 67:480–2
 172. Guilbert MC, Elkouri S, Bracco D, Corriveau MM, Beaudoin N, Dubois MJ, Bruneau L, Blair JF: Arterial trauma during central venous catheter insertion: Case series, review and proposed algorithm. *J Vasc Surg* 2008; 48:918–25
 173. Kulvatunyou N, Heard SO, Bankey PE: A subclavian artery injury, secondary to internal jugular vein cannulation, is a predictable right-sided phenomenon. *Anesth Analg* 2002; 95:564–6
 174. Maschke SP, Rogove HJ: Cardiac tamponade associated with a multilumen central venous catheter. *Crit Care Med* 1984; 12:611–3
 175. Nicholson T, Ettles D, Robinson G: Managing inadvertent arterial catheterization during central venous access procedures. *Cardiovasc Intervent Radiol* 2004; 27:21–5
 176. Shah PM, Babu SC, Goyal A, Mateo RB, Madden RE: Arterial misplacement of large-caliber cannulas during jugular vein catheterization: Case for surgical management. *J Am Coll Surg* 2004; 198:939–44
 177. Sloan MA, Mueller JD, Adelman LS, Caplan LR: Fatal brainstem stroke following internal jugular vein catheterization. *Neurology* 1991; 41:1092–5
 178. Zaidi NA, Khan M, Naqvi HI, Kamal RS: Cerebral infarct following central venous cannulation. *Anaesthesia* 1998; 53:186–91
 179. Lee YH, Kim TK, Jung YS, Cho YJ, Yoon S, Seo JH, Jeon Y, Bahk JH, Hong DM: Comparison of needle insertion and guidewire placement techniques during internal jugular vein catheterization: The thin-wall introducer needle technique *versus* the cannula-over-needle technique. *Crit Care Med* 2015; 43:2112–6
 180. Kim E, Kim BG, Lim YJ, Jeon YT, Hwang JW, Kim HC, Choi YH, Park HP: A prospective randomised trial comparing insertion success rate and incidence of catheterisation-related complications for subclavian venous catheterisation using a thin-walled introducer needle or a catheter-over-needle technique. *Anaesthesia* 2016; 71:1030–6
 181. Song IK, Kim EH, Lee JH, Jang YE, Kim HS, Kim JT: Seldinger *vs.* modified Seldinger techniques for ultrasound-guided central venous catheterisation in neonates: A randomised controlled trial. *Br J Anaesth* 2018; 121:1332–7
 182. Mansfield PF, Hohn DC, Fornage BD, Gregurich MA, Ota DM: Complications and failures of subclavian-vein catheterization. *N Engl J Med* 1994; 331:1735–8
 183. Calvache JA, Rodríguez MV, Trochez A, Klimek M, Stolker RJ, Lesaffre E: Incidence of mechanical complications of central venous catheterization using landmark technique: Do not try more than 3 times. *J Intensive Care Med* 2016; 31:397–402
 184. Lefrant JY, Muller L, De La Coussaye JE, Prudhomme M, Ripart J, Gouzes C, Peray P, Saissi G, Eledjam JJ: Risk factors of failure and immediate complication of subclavian vein catheterization in critically ill patients. *Intensive Care Med* 2002; 28:1036–41
 185. Reeves ST, Roy RC, Dorman BH, Fishman RL, Pinosky ML: The incidence of complications after the double-catheter technique for cannulation of the right internal jugular vein in a university teaching hospital. *Anesth Analg* 1995; 81:1073–6
 186. Bansal R, Agarwal SK, Tiwari SC, Dash SC: A prospective randomized study to compare ultrasound-guided with nonultrasound-guided double lumen internal jugular catheter insertion as a temporary hemodialysis access. *Ren Fail* 2005; 27:561–4
 187. Cajozzo M, Quintini G, Cocchiera G, Greco G, Vaglica R, Pezzano G, Barbera V, Modica G: Comparison of central venous catheterization with and without ultrasound guide. *Transfus Apher Sci* 2004; 31:199–202
 188. Dolu H, Goksu S, Sahin L, Ozen O, Eken L: Comparison of an ultrasound-guided technique *versus* a landmark-guided technique for internal jugular vein cannulation. *J Clin Monit Comput* 2015; 29:177–82

189. Mallory DL, McGee WT, Shawker TH, Brenner M, Bailey KR, Evans RG, Parker MM, Farmer JC, Parillo JE: Ultrasound guidance improves the success rate of internal jugular vein cannulation: A prospective, randomized trial. *Chest* 1990; 98:157–60
190. Milling TJ Jr, Rose J, Briggs WM, Birkhahn R, Gaeta TJ, Bove JJ, Melniker LA: Randomized, controlled clinical trial of point-of-care limited ultrasonography assistance of central venous cannulation: The Third Sonography Outcomes Assessment Program (SOAP-3) Trial. *Crit Care Med* 2005; 33:1764–9
191. Shrestha BR, Gautam B: Ultrasound *versus* the landmark technique: A prospective randomized comparative study of internal jugular vein cannulation in an intensive care unit. *JNMA J Nepal Med Assoc* 2011; 51:56–61
192. Slama M, Novara A, Safavian A, Ossart M, Safar M, Fagon JY: Improvement of internal jugular vein cannulation using an ultrasound-guided technique. *Intensive Care Med* 1997; 23:916–9
193. Teichgräber UK, Benter T, Gebel M, Manns MP: A sonographically guided technique for central venous access. *AJR Am J Roentgenol* 1997; 169:731–3
194. Troianos CA, Jobs DR, Ellison N: Ultrasound-guided cannulation of the internal jugular vein: A prospective, randomized study. *Anesth Analg* 1991; 72:823–6
195. Agarwal A, Singh DK, Singh AP: Ultrasonography: A novel approach to central venous cannulation. *Indian J Crit Care Med* 2009; 13:213–6
196. Denys BG, Uretsky BF, Reddy PS: Ultrasound-assisted cannulation of the internal jugular vein: A prospective comparison to the external landmark-guided technique. *Circulation* 1993; 87:1557–62
197. Palepu GB, Deven J, Subrahmanyam M, Mohan S: Impact of ultrasonography on central venous catheter insertion in intensive care. *Indian J Radiol Imaging* 2009; 19:191–8
198. Verghese ST, McGill WA, Patel RI, Sell JE, Midgley FM, Ruttimann UE: Comparison of three techniques for internal jugular vein cannulation in infants. *Paediatr Anaesth* 2000; 10:505–11
199. Verghese ST, McGill WA, Patel RI, Sell JE, Midgley FM, Ruttimann UE: Ultrasound-guided internal jugular venous cannulation in infants: A prospective comparison with the traditional palpation method. *ANESTHESIOLOGY* 1999; 91:71–7
200. Karakitsos D, Labropoulos N, De Groot E, Patrianakos AP, Kouraklis G, Poularas J, Samonis G, Tsoutsos DA, Konstadoulakis MM, Karabinis A: 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
201. Grebenik CR, Boyce A, Sinclair ME, Evans RD, Mason DG, Martin B: NICE guidelines for central venous catheterization in children: Is the evidence base sufficient? *Br J Anaesth* 2004; 92:827–30
202. Airapetian N, Maizel J, Langelles F, Modeliar SS, Karakitsos D, Dupont H, Slama M: Ultrasound-guided central venous cannulation is superior to quick-look ultrasound and landmark methods among inexperienced operators: A prospective randomized study. *Intensive Care Med* 2013; 39:1938–44
203. Turker G, Kaya FN, Gurbet A, Aksu H, Erdogan C, Atlas A: Internal jugular vein cannulation: An ultrasound-guided technique *versus* a landmark-guided technique. *Clinics (Sao Paulo)* 2009; 64:989–92
204. Zanolli GR, Baldisserotto M, Piva J: How useful is ultrasound guidance for internal jugular venous access in children? *J Pediatr Surg* 2018; 53:789–93
205. Sulek CA, Blas ML, Lobato EB: A randomized study of left *versus* right internal jugular vein cannulation in adults. *J Clin Anesth* 2000; 12:142–5
206. Gualtieri E, Deppe SA, Sipperly ME, Thompson DR: Subclavian venous catheterization: Greater success rate for less experienced operators using ultrasound guidance. *Crit Care Med* 1995; 23:692–7
207. Fragou M, Gravvanis A, Dimitriou V, Papalois A, Kouraklis G, Karabinis A, Saranteas T, Poularas J, Papanikolaou J, Davlouros P, Labropoulos N, Karakitsos D: Real-time ultrasound-guided subclavian vein cannulation *versus* the landmark method in critical care patients: A prospective randomized study. *Crit Care Med* 2011; 39:1607–12
208. Oh AY, Jeon YT, Choi EJ, Ryu JH, Hwang JW, Park HP, Do SH: The influence of the direction of J-tip on the placement of a subclavian catheter: Real time ultrasound-guided cannulation *versus* landmark method: A randomized controlled trial. *BMC Anesthesiol* 2014; 14:11
209. Aouad MT, Kanazi GE, Abdallah FW, Moukaddem FH, Turbay MJ, Obeid MY, Siddik-Sayyid SM: Femoral vein cannulation performed by residents: A comparison between ultrasound-guided and landmark technique in infants and children undergoing cardiac surgery. *Anesth Analg* 2010; 111:724–8
210. Alderson PJ, Burrows FA, Stemp LI, Holtby HM: Use of ultrasound to evaluate internal jugular vein anatomy and to facilitate central venous cannulation in paediatric patients. *Br J Anaesth* 1993; 70:145–8
211. Hayashi H, Amano M: Does ultrasound imaging before puncture facilitate internal jugular vein cannulation?: Prospective randomized comparison with landmark-guided puncture in ventilated patients. *J Cardiothorac Vasc Anesth* 2002; 16:572–5
212. Armstrong PJ, Cullen M, Scott DH: The “SiteRite” ultrasound machine: An aid to internal jugular vein cannulation. *Anaesthesia* 1993; 48:319–23
213. Ezaru CS, Mangione MP, Oravitz TM, Ibinson JW, Bjerke RJ: Eliminating arterial injury during central

- venous catheterization using manometry. *Anesth Analg* 2009; 109:130–4
214. Gillman LM, Blaivas M, Lord J, Al-Kadi A, Kirkpatrick AW: Ultrasound confirmation of guidewire position may eliminate accidental arterial dilatation during central venous cannulation. *Scand J Trauma Resusc Emerg Med* 2010; 18:39
 215. Bowdle A, Jelacic S, Togashi K, Ferreira R: Ultrasound identification of the guidewire in the brachiocephalic vein for the prevention of inadvertent arterial catheterization during internal jugular central venous catheter placement. *Anesth Analg* 2016; 123:896–900
 216. Amir R, Knio ZO, Mahmood F, Oren-Grinberg A, Leibowitz A, Bose R, Shaefi S, Mitchell JD, Ahmed M, Bardia A, Talmor D, Matyal R: Ultrasound as a screening tool for central venous catheter positioning and exclusion of pneumothorax. *Crit Care Med* 2017; 45:1192–8
 217. Arellano R, Nurmohamed A, Rumman A, Day AG, Milne B, Phelan R, Tanzola R: The utility of transthoracic echocardiography to confirm central line placement: An observational study. *Can J Anaesth* 2014; 61:340–6
 218. Bedel J, Vallée F, Mari A, Riu B, Planquette B, Geeraerts T, Génestal M, Minville V, Fourcade O: Guidewire localization by transthoracic echocardiography during central venous catheter insertion: A periprocedural method to evaluate catheter placement. *Intensive Care Med* 2013; 39:1932–7
 219. Kim SC, Gräff I, Sommer A, Hoefft A, Weber S: Ultrasound-guided supraclavicular central venous catheter tip positioning via the right subclavian vein using a microconvex probe. *J Vasc Access* 2016; 17:435–9
 220. Yoshimura M, Nakanishi T, Sakamoto S, Toriumi T: Confirmation of optimal guidewire length for central venous catheter placement using transesophageal echocardiography. *J Clin Anesth* 2016; 35:58–61
 221. Mahmood F, Sundar S, Khabbaz K: Misplacement of a guidewire diagnosed by transesophageal echocardiography. *J Cardiothorac Vasc Anesth* 2007; 21:420–1
 222. Sawchuk C, Fayad A: Confirmation of internal jugular guide wire position utilizing transesophageal echocardiography. *Can J Anaesth* 2001; 48:688–90
 223. Alonso-Quintela P, Oulego-Erroz I, Rodriguez-Blanco S, Muñoz-Fontan M, Lapeña-López-de Armentia S, Rodriguez-Nuñez A: Location of the central venous catheter tip with bedside ultrasound in young children: Can we eliminate the need for chest radiography? *Pediatr Crit Care Med* 2015; 16:e340–5
 224. Baviskar AS, Khatib KI, Bhoi S, Galwankar SC, Dongare HC: Confirmation of endovenous placement of central catheter using the ultrasonographic “bubble test.” *Indian J Crit Care Med* 2015; 19:38–41
 225. Blans MJ, Endeman H, Bosch FH: The use of ultrasound during and after central venous catheter insertion *versus* conventional chest X-ray after insertion of a central venous catheter. *Neth J Med* 2016; 74:353–7
 226. Cortellaro F, Mellace L, Paglia S, Costantino G, Sher S, Coen D: Contrast enhanced ultrasound *vs.* chest x-ray to determine correct central venous catheter position. *Am J Emerg Med* 2014; 32:78–81
 227. Duran-Gehring PE, Guirgis FW, McKee KC, Goggans S, Tran H, Kalynych CJ, Wears RL: The bubble study: Ultrasound confirmation of central venous catheter placement. *Am J Emerg Med* 2015; 33:315–9
 228. Galante O, Slutsky T, Fuchs L, Smoliakov A, Mizrakli Y, Novack V, Brotfein E, Klein M, Frenkel A, Koifman L, Almog Y: Single-operator ultrasound-guided central venous catheter insertion verifies proper tip placement. *Crit Care Med* 2017; 45:e994–1000
 229. Gekle R, Dubensky L, Haddad S, Bramante R, Cirilli A, Catlin T, Patel G, D’Amore J, Slesinger TL, Raio C, Modayil V, Nelson M: Saline flush test: Can bedside sonography replace conventional radiography for confirmation of above-the-diaphragm central venous catheter placement? *J Ultrasound Med* 2015; 34:1295–9
 230. Kamalipour H, Ahmadi S, Kamali K, Moaref A, Shafa M, Kamalipour P: Ultrasound for localization of central venous catheter: A good alternative to chest x-ray? *Anesth Pain Med* 2016; 6:e38834
 231. Korsten P, Mavropoulou E, Wienbeck S, Ellenberger D, Patschan D, Zeisberg M, Vasko R, Tampe B, Müller GA: The “rapid atrial swirl sign” for assessing central venous catheters: Performance by medical residents after limited training. *PLoS One* 2018; 13:e0199345
 232. Lanza C, Russo M, Fabrizzi G: Central venous cannulation: Are routine chest radiographs necessary after B-mode and colour Doppler sonography check? *Pediatr Radiol* 2006; 36:1252–6
 233. Maury E, Guglielminotti J, Alzieu M, Guidet B, Offenstadt G: Ultrasonic examination: An alternative to chest radiography after central venous catheter insertion? *Am J Respir Crit Care Med* 2001; 164:403–5
 234. Meggiolaro M, Scatto A, Zorzi A, Roman-Pognuz E, Lauro A, Passarella C, Bonaccorso G: Confirmation of correct central venous catheter position in the pre-operative setting by echocardiographic “bubble-test.” *Minerva Anestesiol* 2015; 81:989–1000
 235. Park YH, Lee JH, Byon HJ, Kim HS, Kim JT: Transthoracic echocardiographic guidance for obtaining an optimal insertion length of internal jugular venous catheters in infants. *Paediatr Anaesth* 2014; 24:927–32
 236. Vezzani A, Brusasco C, Palermo S, Launo C, Mergoni M, Corradi F: Ultrasound localization of central vein catheter and detection of postprocedural

- pneumothorax: An alternative to chest radiography. *Crit Care Med* 2010; 38:533–8
237. Weekes AJ, Johnson DA, Keller SM, Efune B, Carey C, Rozario NL, Norton HJ: Central vascular catheter placement evaluation using saline flush and bedside echocardiography. *Acad Emerg Med* 2014; 21:65–72
 238. Weekes AJ, Keller SM, Efune B, Ghali S, Runyon M: Prospective comparison of ultrasound and CXR for confirmation of central vascular catheter placement. *Emerg Med J* 2016; 33:176–80
 239. Wilson SP, Assaf S, Lahham S, Subeh M, Chiem A, Anderson C, Shwe S, Nguyen R, Fox JC: Simplified point-of-care ultrasound protocol to confirm central venous catheter placement: A prospective study. *World J Emerg Med* 2017; 8:25–8
 240. Kim YI, Ryu JH, Min MK, Park MR, Park SC, Yeom SR, Han SK, Park SW, Lee SH: Usefulness of ultrasonography for the evaluation of catheter misplacement and complications after central venous catheterization. *Clin Exp Emerg Med* 2018; 5:71–5
 241. Janik JE, Cothren CC, Janik JS, Hendrickson RJ, Bensard DD, Partrick DA, Karrer FM: Is a routine chest x-ray necessary for children after fluoroscopically assisted central venous access? *J Pediatr Surg* 2003; 38:1199–202
 242. Pang H, Chen Y, He X, Zeng Q, Ye P: Fluoroscopy-guided subclavian vein catheterization in 203 children with hematologic disease. *Medicine (Baltimore)* 2018; 97:e13527
 243. Andropoulos DB, Stayer SA, Bent ST, Campos CJ, Bezold LI, Alvarez M, Fraser CD: A controlled study of transesophageal echocardiography to guide central venous catheter placement in congenital heart surgery patients. *Anesth Analg* 1999; 89:65–70
 244. Wirsing M, Schummer C, Neumann R, Steenbeck J, Schmidt P, Schummer W: Is traditional reading of the bedside chest radiograph appropriate to detect intraatrial central venous catheter position? *Chest* 2008; 134:527–33
 245. Francis KR, Picard DL, Fajardo MA, Pizzi WF: Avoiding complications and decreasing costs of central venous catheter placement utilizing electrocardiographic guidance. *Surg Gynecol Obstet* 1992; 175:208–11
 246. Gebhard RE, Szmuk P, Pivalizza EG, Melnikov V, Vogt C, Warters RD: The accuracy of electrocardiogram-controlled central line placement. *Anesth Analg* 2007; 104:65–70
 247. McGee WT, Ackerman BL, Rouben LR, Prasad VM, Bandi V, Mallory DL: Accurate placement of central venous catheters: A prospective, randomized, multi-center trial. *Crit Care Med* 1993; 21:1118–23
 248. Pérez-Díez D, Salgado-Fernández J, Vázquez-González N, Calviño-Santos R, Vázquez-Rodríguez JM, Aldama-López G, García-Barreiro JJ, Castro-Beiras A: Images in cardiovascular medicine: Percutaneous retrieval of a lost guidewire that caused cardiac tamponade. *Circulation* 2007; 115:e629–31
 249. Lin YN, Chou JW, Chen YH, Liu CY, Ho CM: A 20-year retained guidewire: Should it be removed? *QJM* 2013; 106:373–4
 250. Gunduz Y, Vatan MB, Osken A, Cakar MA: A delayed diagnosis of a retained guidewire during central venous catheterisation: A case report and review of the literature. *BMJ Case Rep* 2012; 2012
 251. Bugnicourt JM, Belhomme D, Bonnaire B, Constans JM, Manaouil C: Posterior cerebral infarction following loss of guide wire. *Case Rep Neurol Med* 2013; 2013:164710
 252. Hemsinli D, Mutlu H, Altun G, Pulathan Z, Ozdemir AC: An unexpected image on a chest radiograph. *Scott Med J* 2017; 62:156–8
 253. Ho L, Spanger M, Hayward P, McNicol L, Weinberg L: Missed carotid artery cannulation: A line crossed and lessons learnt. *Anaesth Intensive Care* 2014; 42:793–800
 254. Abeysinghe V, Xu JH, Sieunarine K: Iatrogenic injury of vertebral artery resulting in stroke after central venous line insertion. *BMJ Case Rep* 2017; 2017
 255. Jackson D, Turner R: Power analysis for random-effects meta-analysis. *Res Synth Methods* 2017; 8:290–302
 256. Team RC: R: A Language and Environment for Statistical Computing. 2019. Available at: <http://www.R-project.org/>. Accessed November 11, 2019.
 257. Schwarzer G: Meta: An R package for meta-analysis (4.9-4). *R News* 2007; 7:40–5
 258. Schwarzer G, Carpenter JR, Rücker G: *Metasens: Advanced Statistical Methods to Model and Adjust for Bias in Meta-Analysis*. 2017. Available at: <https://rdrr.io/cran/metasens/>. Accessed November 11, 2019.