Safety in the operating room

Author: Joyce A Wahr, MD, FAHA
Section Editor: Roberta Hines, MD
Deputy Editor: Nancy A Nussmeier, MD, FAHA

All topics are updated as new evidence becomes available and our peer review process is complete.

Literature review current through: Aug 2022. | **This topic last updated:** Aug 31, 2021.

INTRODUCTION

Although patient safety in the operating room (OR) has improved in the last decades, significant risks remain [1]. Adverse events that may occur include those that are subtle and delayed (eg, a central line-associated bloodstream infection) or dramatic and immediate (eg, a fire). Human errors and/or communication failures cause or contribute to most adverse events. Thus, well-designed systems must be in place to prevent and detect errors and reduce harm when a mistake occurs.

Safety issues also exist for the clinicians caring for patients in the OR (eg, infection risk due to contact, droplet exposure, or needle stick injury).

This topic reviews approaches to reduce risk for various hazards to improve patient and provider safety in the OR and other settings where interventional procedures are performed. Details regarding safety in labor and delivery settings are available in a separate topic. (See "Reducing adverse obstetric outcomes through safety sciences".)

HUMAN ERROR: TYPES AND PREVENTION

The science of safety is based on the premise that everyone makes errors which may result in adverse outcomes. Studies have noted that more than one-half of perioperative adverse events were due to errors and were probably preventable [2-4]. Specific processes can be implemented to prevent errors in execution, planning, or problem solving, as well as poor communication, inadequate teamwork, and rules violations, and to minimize the adverse impact of such errors [4-6].

By definition, errors are unintentional; they involve the use of a flawed decision or plan to achieve an aim, or the failure to carry out a planned action as intended. Many are due to inherent cognitive processes, which may lead to action-based or decision-based errors, as noted below [7,8]. Since cognitive processes are similar in all humans, situations leading an individual to make an error are likely to result in repeated errors made by others. Notably, many so-called cognitive errors are actually violations, when the clinician willfully deviates from a practice accepted to be optimal. Such violations are generally not malevolent (the clinician does not intend harm), but occur due to perceived convenience or an attempt to increase productivity (eg, not performing appropriate hand hygiene). Other errors occur due to technical problems or communication failures [2,9,10].

Specific types of errors and general prevention strategies are noted below:

- **Action-based (fast thinking) errors** – Action-based (ie, skill-based) errors involve thinking that is immediate, associative, unconscious, and effortless (often involving familiar "rules") [11-13]. Examples include:

  - Interruption in an often performed sequence of actions (or "schema"), such that a step is skipped or repeated erroneously (eg, forgetting the second dilution in a "double-dilution," of a vasopressor)

  - Application of a good rule in the wrong situation (administering atropine to treat a bradyarrhythmia caused by electrocautery interference with pacemaker function)

  - Error in pattern matching (chest pain assumed to be due to myocardial infarction when the cause is dissection of an aortic aneurysm)

  Prevention of action-based errors involves a brief conscious effort to check that the planned action is the correct one and verify the expected outcome after the action (ie, stop, think, act, and reflect [Star]). Specific strategies include:

  - Pausing briefly when performing a schema to verify the steps

  - Avoiding distractions during critical tasks

  - Implementing evidence-based clinical practice guidelines

- Standardizing techniques so that deviation from the expected result is more easily recognized
- Building redundancy into systems (eg, two person checks)

- **Decision-based errors (slow thinking) errors** – Decision-based errors involve thinking that is slow, reflective, deductive, conscious, effortful, and logical [11-13]. These may occur when the presenting facts match no recognizable pattern or when no "schema," fits the situation. Errors in these contexts are due to faulty knowledge or judgement. They are more insidious and difficult to identify and correct than action-based errors [14,15]. Critical thinking failure and cognitive biases may lead to inadequate risk assessment, incorrect diagnosis, and/or incorrect choices of treatment [15,16]. Such errors often occur during a crisis, and may be compounded by persistence on an incorrect path.

  Prevention of decision-based errors involves improving awareness and insight into cognitive biases and increase consideration of alternative possibilities [17]. Specific strategies include:

  - Simulation training to develop "cognitive walkthrough," strategies for specific clinical scenarios. Such training can develop a pattern or rule for even rare and seldom encountered events. (See 'Simulation training' below.)
  - Cognitive aids to decrease reliance on memory of "rules," through mnemonics, algorithms, and computerized decision support. Such aids may be particularly important during emergencies and can provide guidance for situations which otherwise would require "thinking from first principles." (See "Cognitive aids for perioperative emergencies".)
  - Implementation of evidence-based clinical practice guidelines. (See 'Implementation of evidence-based best practices' below.)

- **Technical errors** – Technical errors typically occur when the difficulty of the task exceeds the clinician's proficiency, or when the patient’s anatomy is abnormal and complex [2,9,10]. Examples include placing a needle in the carotid artery instead of the internal jugular vein or intubating the esophagus instead of the trachea or intubating the esophagus.

  Preventing or minimizing technical errors involves:

  - Implementing known safety precautions for skill-based tasks (eg, use of ultrasound guidance for central line placement, use of end-tidal carbon dioxide [$ETCO_2$] to verify endotracheal intubation).

- Building redundancy into systems (eg, two person checks, use of both ultrasound guidance and transduction of a waveform from an 18 gauge needle or catheter that is inserted into a central vein prior to insertion of a larger 8.5 F introducer sheath).

- Conscious evaluation of the complexity of the task and one's own proficiency and inviting a "second pair of hands," if additional proficiency or expertise would be beneficial.

- **Communication-based errors** – Communication errors resulting in an unintended act are the leading root cause of serious adverse events that result in patient harm (eg, retained surgical items (see "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management", section on 'Work environment')) [15,18-27]. In one study, nearly one-third of all OR communications resulted in partial failure (eg, poor timing, missing or inaccurate content, wrong audience, ineffective communication resulting in failure to resolve the issue) [21]. In another study, ineffective communication was a contributing factor in two-thirds of 50 anonymous reports of critical incidents involving anesthesiologists [15].

  Prevention of errors based on poor communication includes the following strategies:

  - Use of a preoperative briefing. (See 'Briefings' below.)

  - Use of structured communication. (See 'Structured communication' below.)

  - Teamwork training to teach communication skills [28-38]. (See 'Team training' below.)

GENERAL APPROACHES TO RISK REDUCTION

General approaches to risk reduction during surgery and other interventional procedures include review of the patient's informed consent, use of timeouts, surgeon-led briefings and team debriefings, standardized checklists for routine cases and cognitive aids during emergencies, techniques to minimize distractions and disruptions, structured communication, and formal handoff procedures during transitions of care.

Reviews of informed consent — Initial review of the surgical consent occurs in the preoperative holding area. This critical part of preparation confirms the patient's identity and their understanding of the specific surgical or interventional procedure to be performed, as well as the site and side of the planned procedure. A 2020 systematic review noted that communication about postoperative care (eg, possible adverse postoperative events, shared decision-making) between patients and anesthesia professionals was rare (3.6 percent of 1284 consultations) was rare even though most patients preferred to be informed of all important aspects of perioperative care [39]. (See 'Wrong procedure or wrong site' below.)

Details for obtaining appropriate informed consent are discussed separately. (See "Preoperative evaluation for anesthesia for noncardiac surgery", section on 'Consent and decision making' and "Informed procedural consent".)

Timeouts — The initial timeout process begins in the preoperative holding area (table 1). Documents are checked to prevent errors by verifying patient identity using dual identifiers, as well as verifying the procedure, side, site, and/or level (see 'Wrong procedure or wrong site' below). This preoperative timeout process should include:

- Participation of the patient or a surrogate to verify identifying information
- Participation of at least two medical professionals
- Documentation in the chart

If a regional block is planned, a separate timeout is necessary just before beginning the process of placing the block. Wrong-side blocks occur as frequently as wrong-side surgical procedures [40-42].

Just before surgical incision, a final brief (less than one minute) timeout is performed with participation of the entire OR team [43]. The patient's identity with dual identifiers, surgical procedure to be performed, and surgical site, side, or level are carefully confirmed in this final timeout.

Briefings — Before surgery, a surgeon-led preoperative briefing or "huddle," that goes beyond a simple checklist should also be performed to ensure thorough communication among all members of the team before beginning a procedure. The World Health Organization (WHO) surgical safety checklist incorporates such a briefing (table 2). Briefings accomplish the following goals [44-49]:

- Development of a shared mental model of the surgical plan and procedures [50]
- Anticipation of risks
- Reduction of trips to retrieve missing equipment
- Completion of all critical steps
- Improvement in teamwork and safety

Standardized preoperative briefings include participation of the entire OR team (surgeon, anesthesiologist, circulating nurse, and scrub technician) and have the following elements (table 2):

- Introducing each team member and their role.
- Rechecking patient identity (using dual identifiers) and consent, the surgical procedure to be performed, and the site, side, or level of surgery (table 1).
- Identifying the patient's medical status (table 3), recent laboratory and/or radiology results, and the management plan for medical comorbidities such as diabetes.
- Ensuring team understanding of goals and critical steps for the procedure, as well as contingency plans.
- Discussing antibiotic administration (if appropriate), including antibiotic selection, initial dosing and timing (table 4), and plans for re-dosing (if appropriate). (See "Antimicrobial prophylaxis for prevention of surgical site infection in adults", section on 'Antibiotic administration'.)
- Discussing venous thrombosis prophylaxis (if appropriate) (table 5). (See "Prevention of venous thromboembolic disease in adult nonorthopedic surgical patients".)
- Evaluating fire risk and discussing mitigation strategies (eg, reduction of fraction of inspired oxygen [FiO_2]). (See "Fire safety in the operating room".)
- Verifying blood product availability (if appropriate). (See "Perioperative blood management: Strategies to minimize transfusions".)
- Determining ideal monitoring strategies and availability of equipment.
- Verifying availability and proper functioning of all necessary surgical equipment and instruments, and identifying any implant concerns.
- Discussing appropriate patient positioning, padding, and skin preparation. (See "Patient positioning for surgery and anesthesia in adults".)
- Planning postoperative disposition (eg, post-anesthesia care unit [PACU] or intensive care unit [ICU]).
- Inviting all team members to ask questions and to speak up regarding any concerns before or during the procedure [51].

Data suggest that briefings result in better patient outcomes and improved staff performance. In one Veterans Administration (VA) study that included more than 180,000 surgical procedures in the years 2006 to 2008, team training in use of briefings, debriefings, and checklists at 74 VA facilities reduced annual mortality by 18 percent compared with a 7 percent reduction during this time period at 34 VA facilities that did not implement training [52]. Other studies have documented improvements in team compliance with best practices after implementation of briefings (eg, antibiotic and deep venous thrombosis prophylaxis) [47,49,53].

Checklists — Checklists ensure that no steps of a procedure are missed. Examples include:

- **Standardized surgical team checklist** – A standardized checklist such as the World Health Organization (WHO) surgical safety checklist should be used in the OR before starting any surgical or other interventional case [54]. The WHO checklist provides a set of elements to be checked at three stages of any surgical procedure (sign in, timeout, and sign out) (table 2). An appropriate checklist is ideally included as part of a surgeon-led briefing. (See 'Briefings' above.)

  A 2018 international meta-analysis of 11 observational studies that included more than 450,000 patients noted that use of the WHO checklist was associated with reduced postoperative mortality (odds ratio [OR] 0.75, 95% CI 0.62-0.92) and complication rates (OR 0.73 (0.61-0.88), compared with no checklist use [55]. Previous systematic reviews noted similar findings [56,57]. Some studies included in these meta-analyses emphasized adherence to all aspects of care embedded in the checklist. Benefits of a checklist depend on relevant design and content, adequate introduction and training, appropriate implementation, and enthusiastic adoption by the surgical team, as well as full compliance with its use [58-60]. The adaptive work of the team may be the critical factor that generates measurable improvements [58]. Partial use or poor implementation of use of a checklist may yield only limited or short-term improvements [55,61,62].

- **Standardized anesthesia machine checkout** – Another checklist routinely used in the intraoperative setting is the anesthesia machine checkout performed by the anesthesia provider (table 6). Meticulous adherence to published guidelines for pre-use checkout of the anesthesia machine and equipment would likely avoid most critical incidents related to anesthesia workstation misuse or failure, as discussed separately. (See "Anesthesia machines: Prevention, diagnosis, and management of malfunctions", section on 'Standardized anesthesia machine checkout' and 'Equipment errors' below.)

- **Cognitive aids for emergencies -** Cognitive aids for emergency situations are another type of checklist. These should be immediately available in the OR and other interventional suites, as discussed separately. (See "Cognitive aids for perioperative emergencies".)

Techniques to minimize distractions and disruptions — Distractions occur frequently during surgery (typically 11 to 12 events per hour) [63,64]. For example, equipment alarms occurred at a rate of 1.2 per minute in one cardiac surgical study [65]. In addition to alarms, conversation and even music can disrupt surgical flow and create excessive noise levels interfering with communication [66]. Door openings into the OR are distracting for some clinicians. In one study, this occurred more than 30 times during each hour [67,68]. Another cause of distraction is concentration on untangling multiple intravenous (IV) tubing lines, monitoring wires, and cables connected to the patient [69].

Flow disruptions and distractions cause technical errors that have been associated with adverse events and mortality [70-73]. Evidence suggests that the accumulation of minor events decreases the surgical team's ability to compensate for a major event [74].

Specific techniques to minimize distractions include:

- Limiting the number of individuals in the room. Each additional person increases the number of potential distractions due to door openings and additional conversation, and also increases the bacterial count in the OR [67,68,75].
- Being cognizant of mental workload of each team member. This workload typically varies across time according the clinician’s discipline [76]. For example:
  - Anesthesiologists benefit if noise and distractions are limited during induction of general anesthesia.
  - Surgeons benefit if interruptions are limited to only those that are critical. Questions about cases for the following day can wait until the end of this procedure.
  - Nurses and technicians benefit from minimizing distraction, multitasking, and time pressure during performance of their critical activities (eg, searching for a missing sponge, counting protocols) — (See "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management", section on 'Standardized count protocols' and "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management", section on 'Count discrepancies'.)
- Reducing noise level from all sources (eg, limiting conversations, silencing noncritical alarms, ensuring only soft [or absent] music, turning all beepers to vibrate instead of ring mode [with one team member assigned to manage all pages]).

  Notably, auditory cues that are less loud may be helpful. For example, an auditory pulse oximetry display enhanced with tremolo and brightness allowed more accurate detection of values outside the target range [77].

Structured communication — Structured communication is used in other high-risk industries (eg, nuclear power, aviation, military operations), and is often used in the OR, particularly during complex surgical cases or crisis situations [21,78-81]. Structured communication includes:

- Identification of the intended recipient by beginning a communication with the individual's name.
- Use of closed loop communication (ie, speak-back or call-back) by requiring the receiver to repeat the message as heard, after which the sender verifies accuracy.
- Use of standardized words (eg, alpha, bravo, Charlie) and numbers (eg, "one one" for eleven since pronunciation of eleven sounds similar to seven).

Debriefings — After surgery, a postoperative debriefing is used to ensure that all steps were completed, as well as to identify underappreciated hazards, learn from mistakes that occurred during the case, and suggest improvements [46,48,49,82,83]. Identification of errors and near-misses during a debriefing are useful to implement improvements that reduce risk (see 'Establishing safety culture' below) [84].

Specific debriefing tasks include:

- Completion and sign off of sponge/equipment counts (see "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management", section on 'Standardized count protocols')
- Completion of all paperwork, with proper labeling that includes patient name and medical record number
- Completion of specimen forms for pathology
- Discussion of transition from the OR to the PACU or ICU or preparation of patient instructions for patients who are returning home on the day of surgery
- Discussion of any equipment problems that were identified and completion of reports for further investigation
- Discussion of any errors made and identification of possible processes to improve safety or efficiency

Handoffs — Formal standardized handoff protocols, including both verbal and written communication, are used during transfer of patient care from one individual or team to another (either in the OR or after transport from OR to the PACU or ICU). Further discussion is available in separate topics. (See "Handoffs of surgical patients" and "Patient handoffs".)

RISK REDUCTION STRATEGIES FOR SPECIFIC HAZARDS

Wrong procedure or wrong site

- **General considerations** – In the United States, wrong-site surgery was the second most frequently reported serious adverse event in the period from 1995 to 2005 (12.8 percent of all events in hospitalized patients) in the Joint Commission Sentinel Event statistics database [85]. The percentage of wrong-site surgery events has remained essentially unchanged for nearly two decades (1072 of 8275 sentinel events [12.9 percent] from 2004 to 2014; 336 of 2563 reported events [13.1 percent] from 2015 to 2017). The incidence of these events varied among institutions (0.09 to 4.5 per 10,000 surgical procedures) [85]. Notably, equal numbers of wrong site events occur in surgical patients within or outside of an OR [18].

  Many such events involve performance of a wrong site nerve block [40-42]. A 2018 systematic review of wrong-site nerve blocks noted an incidence of 0.53 to 5.07 per 10,000 regional blocks [86].

  Factors contributing to wrong patient, wrong procedure, wrong site, or wrong side surgery include poor communication regarding the surgical plan, failure to use site markings, incorrect patient positioning, surgeon fatigue, presence of multiple surgeons, multiple procedures on the same patient, unusual time pressures, emergency operations, and/or unusual patient anatomy [18].

  Despite mandatory timeouts to identify patient, procedure, and laterality (table 1), wrong-site events continue to occur [87,88]. Even when an excellent timeout has been completed, one or more contributing factors may not have been eliminated. Examples include an imaging error or a medical record with charting errors [18].

- **Approaches to risk reduction** – Errors in identifying the correct surgical site can occur at any time in the perioperative period, including during imaging, charting, or preparation of preoperative consent forms [18]. Each step of the process requires a high level of attention beginning with review of the surgical consent and verification of the correct procedure and site, ideally with patient participation (see 'Reviews of informed consent' above and 'Timeouts' above). Use of a preoperative safety checklist that includes a surgeon-led briefing regarding the planned procedure, ideally with participation of all surgical team members, provides an additional opportunity to detect errors (table 2). (See 'Checklists' above and 'Briefings' above.)

For peripheral nerve blocks, the "stop-before-you-block," initiative is designed to prevent administration of regional anesthesia on the wrong side. The anesthesiologist pauses to check the correct side just before needle insertion, thereby interrupting performance of the block [86]. A regional survey of 173 anesthesiologists noted that full compliance with this initiative has not been achieved in the United Kingdom [89-91].

Infection risks

Infection risks for patients

Surgical site infection — Surgical site infections (SSI) are common complications of surgical and other interventional procedures, particularly if wounds are contaminated or dirty. We agree with recommendations for infection prevention noted in various professional guidelines. (See "Overview of the evaluation and management of surgical site infection".)

Implementation of surgical care bundles, or enhanced recovery protocols, is a strategy to reduce SSI risk [92]. Elements managed by anesthesia providers include [93,94] (see "Anesthetic management for enhanced recovery after major noncardiac surgery (ERAS)"):

- **Standard precautions for anesthesia care team members** – Standard precautions include hand hygiene, use of gloves, mask, eye protection, and gowns (when appropriate); high-level disinfection or sterilization of reusable laryngoscopes and video-laryngoscopes; and cleaning of computer keyboards and touchscreen computer monitors (or disinfection if there is obvious soiling or contamination) after each surgical case. (See "Overview of control measures for prevention of surgical site infection in adults".)

- **Antibiotic prophylaxis** – When an antibiotic is indicated preoperatively, most should be administered within 60 minutes of the skin incision or tourniquet inflation to achieve a bactericidal tissue concentration. For antibiotics that require infusion over more than 60 minutes, the infusion should be completed within 60 minutes prior to incision. In all cases, consideration should be given to the time required to achieve therapeutic tissue levels, not just completion of infusions. If a surgical case is greatly delayed such that more than 60 minutes elapse after completion of antibiotic administration, an additional dose may be indicated to preserve tissue concentration. For example, if cephalosporin 2 grams was administered as an initial dose >60 minutes prior to incision, an additional dose of 500 mg would be indicated. Antibiotics should be re-dosed at appropriate intervals (table 4). (See "Antimicrobial prophylaxis for prevention of surgical site infection in adults".)

- **Safe practices for administration of intravenous (IV) medications** – Use safe vial access and injection practices. Note that sterile injectable medications are used as soon as possible after preparation, with prompt disposal of medication syringes and vials at the end of each case or after their expiration date [94-96]. (See "Prevention of perioperative medication errors", section on 'Avoid multiuse vials'.)

  In addition, IV fluids are used as soon as possible after spiking the solution bag. However, no bacterial growth was noted in any samples drawn at the time of preparation and at 24 hours after spiking 1000 mL bags of normal saline (n = 127) or 5% dextrose in water (n = 129) [97].

  Bacterial transmission from the anesthesia work station and anesthesia providers' hands is a root cause of postoperative infections in as many as 16 percent of patients undergoing surgery, including gram-negative, hospital-acquired infection [94,98,99]. One study used fluorescent indicator dye to demonstrate that patient oral contents spread from the hands of the anesthesia provider to most nearby work surface areas in the OR within an hour of endotracheal intubation [100]. Double gloving with removal of the top set of gloves immediately after passing the endotracheal tube reduced the spread of the indicator dye.

- **Maintenance of normothermia** – Normothermia with temperature ≥35.5°C is achieved and maintained throughout a surgical case [92,101-103]. Warming devices are employed if necessary to maintain normothermia, including upper- and lower-body forced-air warming devices and blankets, insulation water mattresses, and devices for warming all IV fluids [103-106]. In some cases, it may be necessary to adjust the OR temperature to maintain body temperature. However, hyperthermia is avoided. (See "Overview of control measures for prevention of surgical site infection in adults", section on 'Maintain normothermia' and "Perioperative temperature management".)

- **Avoidance of hyperglycemia** – Blood glucose level is maintained <180 mg/dL (<10 mmol/L), but hypoglycemia (ie, serum glucose concentration <40 mg/dL [2.2 mmol/L]) is carefully avoided [107]. (See "Perioperative management of blood glucose in adults with diabetes mellitus" and "Overview of control measures for prevention of surgical site infection in adults", section on 'Glucose control'.)

- **Considerations regarding supplemental oxygen** – We do not routinely administer a high fraction of inspired oxygen content (FiO_2). The Centers for Disease Control and Prevention 2017 Guidelines for Prevention of Surgical Site Infection state that the optimal target level, duration, and delivery method of O_2 is an unresolved issue, and that further studies are needed to evaluate the effect of high FiO_2 on SSI and other outcomes [108,109]. (See

"Mechanical ventilation during anesthesia in adults", section on 'Oxygen supplementation and surgical site infection'.)

Although a high FiO_2 may be appropriate for some surgical patients, data are conflicting regarding the benefits of supplementing oxygen (O_2) beyond the level required to achieve normoxemia. In one 2019 meta-analysis of 21 trials, use of a high perioperative FiO_2 did not confer clear benefits, although SSI risk was reduced in patients who received a high FiO_2 under general anesthesia with endotracheal intubation. Conversely, another 2019 meta-analysis of 20 trials concluded that liberal perioperative oxygen administration did not reduce SSI risk [110,111]. A third 2019 meta-analysis of 17 trials reported no definite signal of harm with administration of 80 percent FiO_2 versus 30 to 35 percent FiO_2. Furthermore, a 2018 meta-analysis of 25 randomized trials in 16,037 acutely ill adults who received liberal versus conservative oxygen therapy noted that administration of high FiO_2 increased in-hospital mortality risk (relative risk [RR] 1.21, 95% CI 1.03-1.43) [112].

Central line infection — Catheter-related bloodstream infection (CRBSI) can occur after placement of a central venous catheter (CVC) in perioperative settings. (See "Intravascular catheter-related infection: Prevention".)

A checklist is used during CVC line insertion to ensure adherence to standard CRBSI guidelines, including hand washing, full barrier precautions for patient and anesthesiologist, chlorhexidine for skin disinfection, and avoidance of the groin if possible (table 7). (See "Intravascular catheter-related infection: Prevention", section on 'Catheter teams and use of checklist'.)

After placement of the CVC, contamination is minimized by swabbing the access port with appropriate antiseptic and accessing the port only following fastidious hand hygiene (ie, hand washing with antiseptic-containing soap or alcohol-based gels or foams). Although nonsterile gloves are typically worn, their use does not obviate the need for hand hygiene. (See "Intravascular catheter-related infection: Prevention", section on 'Catheter care'.)

Infection risks for anesthesiologists — Anesthesiologists routinely care for patients known or suspected of harboring infectious pathogens that may be transmitted via contact, droplet, or airborne modes, as well as via needle stick injuries [94,113].

- **Contact or droplet exposure** – Hand hygiene and use of surgical masks in all cases, or properly fitted N95 facemasks when caring for selected patients, are essential practices to prevent transmission of infection, as discussed in a separate topic [114]. (See "Infection prevention: Precautions for preventing transmission of infection".)

- **COVID-19 infection** – Frequent hand hygiene and proper donning and doffing of personal protective equipment (PPE) are essential to prevent transmission of the novel coronavirus disease 2019 (COVID-19 or nCoV) disease or other respiratory infectious agents to health care workers (figure 1 and figure 2) (refer to the Centers for Disease Control and Prevention and the American Society of Anesthesiologists) [94,113,115,116]. (See "Infection prevention: Precautions for preventing transmission of infection".)

  PPE includes gown, eye protection, glove (double glove technique), booties, and a fit-tested disposable N95 respirator mask (picture 1), ideally covered with a face shield or a regular surgical mask to avoid gross contamination with secretions, or a powered air-purifying respirator, also known as an isolation suit (picture 2). Further discussion regarding use of PPE, airway management, and safeguards for the anesthesia machine and other equipment during care of patients with suspected or confirmed COVID-19 is available in a separate topic. (See "COVID-19: Perioperative risk assessment and anesthetic considerations, including airway management and infection control".)

Sharp object injury — Risks for needlestick or sharp object injuries to patients or OR personnel have been reduced due to advances in education, needle disposal, and engineering changes (eg, needleless devices, safety needles) .

Management after potential exposure to a bloodborne pathogen (eg, human immunodeficiency virus [HIV-1], hepatitis B virus [HBV], hepatitis C virus [HCV]) is discussed separately. (See "Prevention of hepatitis B virus and hepatitis C virus infection among health care providers" and "Management of health care personnel exposed to HIV".)

Medication errors — Strategies to prevent medication errors such as administration of the wrong medication, wrong dose, or into the wrong site are reviewed separately. (See "Prevention of perioperative medication errors" and "Prevention of adverse drug events in hospitals".)

Retained surgical items — Prevention and management of accidental loss of surgical equipment (eg, sponges, instruments) within a wound are discussed in a separate topic. (See "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management".)

Equipment errors — Equipment can malfunction, or cause harm by not being available when needed (eg, bronchoscopes that go black when in standby mode). Most often errors due to equipment come from poor design [117]. In our experience, the most often reported incident involving equipment comes from mis-programing or malfunction of infusion devices.

- **General considerations** – Machines and equipment used by anesthesiologists and other OR personnel have been identified as potential causes of harm due to [117-120]:

  - Misuse because of poor training or negligence
  - Poor maintenance and upkeep
  - Poor machine design
  - Inherent risks in the use of each device

- **Approaches to risk reduction**

  - **Standardization of equipment and technology** – Standardization reduces malfunction and human errors [121]. Examples include:

    - Standards for monitoring including continuous noninvasive assessment of oxygenation. (See "Basic patient monitoring during anesthesia", section on 'Pulse oximetry'.)

    - Fail-safe systems for anesthesia machines such as standardized unique pin-indexing systems for gas cylinders and gas lines to prevent delivery of hypoxic gas mixtures. Although not foolproof, such systems add reliability and safety [122]. (See "Anesthesia machines: Prevention, diagnosis, and management of malfunctions", section on 'Compressed gas supply malfunction' and "Anesthesia machines: Prevention, diagnosis, and management of malfunctions", section on 'Proportioning system or pressure sensor shut-off (fail-safe) valve malfunction'.)

    - Standardization of the content and layout of difficult airway carts in all locations within an institution [123].

  - **Checkout of machines and equipment before use** – An anesthesia machine checkout is performed prior to patient arrival in the OR, including presence and functioning of backup systems such as oxygen canisters and manual ventilation devices (Ambu bag, etc) (table 6) [124]. (See "Anesthesia machines: Prevention, diagnosis, and management of malfunctions", section on 'Standardized anesthesia machine checkout'.)

    Checking function of advanced airway management equipment is also necessary before administration of any sedative, opioid, or anesthetic agent since these agents can cause respiratory depression. (See "Airway management for induction of general anesthesia", section on 'Preparation for induction of anesthesia'.)

Injury related to patient positioning

- **General considerations** – Positioning of an anesthetized patient can cause injuries. Examples include peripheral nerve damage (eg, compression or overstretching), pressure sores, deep vein thrombosis, compartment syndrome, and end-organ damage due to position-related hypoxemia and hypotension.

  Details regarding prevention of specific injuries in the supine, Trendelenburg, reverse Trendelenburg, lithotomy, sitting (beach chair), lateral decubitus, and prone positions are discussed separately. (See "Patient positioning for surgery and anesthesia in adults".)

- **Considerations for specific procedures** – Injuries related to positioning for specific procedures are discussed in individual topics:

  - **Sternal retraction** – Use of a sternal retractor after sternotomy, particularly during cardiac surgery with internal mammary dissection, has been associated with brachial plexus injury, upper arm compression by the retractor resulting in radial nerve injury, and exacerbation of cervical spine arthritis symptoms if the patient's head is not completely supported on the head cushion. (See "Anesthesia for coronary artery bypass grafting surgery", section on 'Positioning'.)

  - **Venous air embolism** – Whenever the surgical field is above the level of the right atrium, air may be entrained into the venous system with resultant venous air embolism. Separate topics discuss prevention, detection, and treatment of air embolism in the beach chair sitting position or during sitting craniotomy (table 8). (See "Patient positioning for surgery and anesthesia in adults", section on 'Sitting' and "Anesthesia for craniotomy", section on 'Sitting position'.)

    Venous air embolism may also occur during laparoscopy or endoscopic retrograde cholangiopancreatography [125]. (See "Uncommon complications of endoscopic retrograde cholangiopancreatography (ERCP)", section on 'Portal vein gas and air embolism' and "Air embolism", section on 'Surgery and trauma'.)

Eye injury or vision loss — Corneal abrasions in the perioperative period are common but typically preventable. Postoperative vision loss is a rare injury that has been reported after procedures in the prone position (eg, spine surgery). Eye injuries are discussed separately. (See "Postoperative visual loss after anesthesia for nonocular surgery".)

Retained surgical items — A surgical item such as a surgical sponge, instrument, tool, or device may be unintentionally left inside the patient at the completion of a surgical procedure. Prevention and management of this problem are discussed separately. (See "Retained surgical sponge (gossypiboma) and other retained surgical items: Prevention and management".)

Radiation injury — Risks of exposure of patients and OR personnel to ionizing radiation and approaches to risk reduction are discussed separately. (See "Radiation-related risks of imaging" and "Anesthesia for magnetic resonance imaging and computed tomography procedures", section on 'Radiation risks'.)

Electrical injury — Electrical injury can cause respiratory paralysis, seizures, muscle contractions, or ventricular fibrillation [126]. Electricity also dissipates energy and increases temperature in body tissues, which may cause burns or cellular death. Patients and staff are at risk of electrical shock or electrocution if they come into contact with a defective device (or a "hot," wire); electricity can flow through their body into the ground. For staff, flow would be into the floor. For patients, flow would be into the OR table or another grounded surface.

- **General precautions to prevent electrical injury in the OR** – Regulations for OR environments mandate institutional risk management for potential electrical injuries by using one of two methods in each OR (see "Environmental and weapon-related electrical injuries"):
  - Making the entire OR an isolated power source, whereby any leak of electrical current is recognized by the line isolation monitor and an alarm sounds.
  - Ensuring that each electrical device in the OR is equipped with a ground fault circuit interrupter, whereby any leak of electrical current trips the power outlet connecting the faulty device to electricity.
- **Precautions during use of electrocautery**
  - Electrocautery devices may cause thermal burns, hemorrhage, device failure, or fire. Strategies to prevent these complications are discussed separately. (See "Overview of electrosurgery".)
  - Patients with a pacemaker or implantable cardioverter-defibrillator require special precautions because of the electromagnetic interference caused by electrocautery, particularly if a monopolar device is employed. Management of these implantable electronic devices in the perioperative setting is described in a separate topic (algorithm 1 and algorithm 2). (See "Perioperative management of patients with a pacemaker or implantable cardioverter-defibrillator".)
  - Patients with neuromodulation devices such as deep brain stimulators, vagal nerve stimulators, spinal cord stimulators, etc, continue to increase in numbers; nearly all

should be turned off prior to surgery, and electrocautery can reprogram the devices, or cause the tip of the electrode to heat up [127].

Operating room fires — Most OR fires are preventable with communication and appropriate education, including assessment of risk during the briefing or timeout. Causes and prevention of fires in the OR are reviewed separately (algorithm 3 and algorithm 4). (See "Fire safety in the operating room".)

Accidental awareness during anesthesia — Recognition, prevention, and management of a possible intraoperative awareness event (ie, intraoperative consciousness with postoperative recall of intraoperative events) are discussed in a separate topic. (See "Accidental awareness after general anesthesia".)

INSTITUTIONAL APPROACHES TO SAFETY IMPROVEMENT

Institutional interventions that improve safety in the OR include maintaining hospital accreditation; implementing incident reporting, team training, and simulation training; applying appropriate evidence-based best practices; and establishing a culture of safety.

Hospital accreditation — The Joint Commission has set national patient safety goals; hospital accreditation depends on demonstration of implementation of elements of performance measures and improvements [128].

Implementation of evidence-based best practices — Clinical practice guidelines are defined by the Institute of Medicine (IOM) as "statements that include recommendations intended to optimize patient care, that are informed by a systematic review of evidence and an assessment of the benefits and harms of alternative care options" [129]. Examples in the OR include antibiotic administration, glycemic control, and maintenance of normothermia [92]. Another example is establishment of guidelines for overlapping surgery (defined as more than one procedure performed by the same primary surgeon with scheduling such that the start time of one procedure overlaps with the end time of another) [130].

Widespread implementation of evidence-supported guidelines typically requires several years [131]. The IOM has recommended that wording in guidelines supported by strong evidence should include measurements that can be recorded by the institution so that adherence to standards can be tracked [132]. (See "Overview of clinical practice guidelines", section on 'Effects of guidelines on practice' and "Overview of clinical practice guidelines", section on 'Implementing practice guidelines'.)

Team training — Team training programs for OR personnel (eg, surgeons, anesthesiologists, nurses, scrub technicians) teach effective communication strategies, how to conduct effective timeouts and briefings, how to challenge other team members when a safety issue is identified, conflict management, and implementation of safe care transitions. Such training decreases communication failures, reduces technical errors, and improves team member satisfaction [32-38,133]. Similar team training efforts have been successfully implemented in obstetrical units. (See "Reducing adverse obstetric outcomes through safety sciences", section on 'Teamwork training'.)

In one large study in the Veteran's Administration Hospital system, surgical mortality was reduced after formal medical team training based on the aviation-style non-technical skills training that included crew resource management (CRM) tenets [52,134]. This training included communication techniques, situational awareness, leadership, and conflict resolution [36,37]. Another teamwork training program is Team Strategies and Tools to Enhance Performance and Patient Safety (TeamSTEPPS), created and implemented by the Agency for Healthcare Research and Quality (AHRQ), and not strictly based on CRM tenants [32,38]. Positive effects of TeamSTEPPS training include reduced overall surgical morbidity and mortality. However, evidence indicates that training must be repeated on a regular basis to maintain benefit [32].

Simulation training — Simulation training that teaches crews to work together in simulated crisis situations is also critically important in aviation safety. In surgical and anesthetic settings, simulation has been used to:

- Teach nontechnical skills (eg, teamwork and communication) [29-31,135].
- Test interventions to reduce error [136].
- Develop and practice crisis protocols [33,137-143], with standardized simulation-based assessment that can identify performance gaps and opportunities for improvement [144]. (See "Reducing adverse obstetric outcomes through safety sciences", section on 'Simulation and drills'.)
- Understand effects of stress and fatigue [145-148]. In a 2019 meta-analysis of nearly 120,000 surgical procedures performed during daytime hours versus more than 46,000 procedures performed during after-hours shifts, mortality was lower for cases performed during the daytime (odds ratio [OR] 0.67, 95% CI 0.51-0.89), as was morbidity (OR 0.71, 95% CI 0.53-0.94) [149].
- Develop technical skills such as airway management, ultrasound-guided regional block, and central line placement. [135].

Simulation training is often conducted at a high-fidelity simulation center using programed manikins and elaborate scenarios [33,150]. However, effective interdisciplinary simulation training in the actual clinical environment can be done without any specific tools. Teams simply walk and talk through a simulated crisis by identifying roles, specifying steps to be taken, and building teamwork [151,152].

Incident reporting — Incident registries have been used to identify and reduce risks in settings and situations that have resulted in errors committed by an individual or team [153]. Although there has been a proliferation of incident reporting registries, there is no clear evidence that these significantly change health care [153]. However, reported information can be used to effect improvements. For example, reviews of the Closed Claims Database in anesthesiology have led to significant changes in anesthetic and surgical practice resulting in risk reduction for cardiac arrest after spinal anesthesia, OR fires, and positioning injuries (eg, nerve injuries, brain injury associated with beach chair positioning, postoperative vision loss associated with prone spine surgery) [154].

Other incident registries are focused on contemporaneous reporting with immediate review of near-misses and adverse events to rapidly identify system vulnerabilities. For example, the American Society of Anesthesiologists (ASA) established the Anesthesia Incident Reporting System (AIRS) in 2011 for reports of near misses or actual events by any anesthesia provider who may choose to file the report with either anonymity or confidentiality [155]. Other examples are the Canadian Anesthesia Incident Reporting System (CAIRS) and the Australia and New Zealand Tripartite Date Committee (ANZTADC) system [156,157]. Institutional implementation of mandatory reporting of adverse events detected with anesthesia information management systems may decrease the incidence of preventable events [158].

Another database of mandatory medical device reports submitted to the FDA is managed by the Manufacturer and User Facility Device Experience (MAUDE). Such registries are modeled on the Aviation Safety Reporting System [159].

Monitoring for any intraoperative deviation from optimal clinical care (ie, nonroutine events) has been suggested for perioperative safety research. In one study of video recordings from 511 cases, one or more nonroutine events occurred in 22 percent [160]. The most common contributory factors involved human factors and included medication errors or equipment issues (37 percent), and patient-related factors involving cardiovascular comorbidity (37 percent) or the airway (33 percent).

Establishing safety culture — A just safety culture holds each individual accountable for their actions [161,162].

Unit-based safety culture programs have been designed for the OR and other hospital settings to accomplish the following goals:

- Provide education to improve awareness about patient safety and quality of care.
- Empower staff to take charge, voice concerns, and improve safety in their unit.
- Create partnerships between units and hospital managers to improve organizational culture and provide resources for unit improvement efforts.
- Provide tools to investigate and learn from defects, foster excellence, and promote resilience [163,164].

A pre- and post-implementation evaluation of a Comprehensive Unit-Based Safety Program (CUSP) in two surgical intensive care (ICU) units noted improvement in safety culture and reduction in ICU length of stay, medication errors, and possibly nursing turnover [165-167]. Elements of CUSP include:

- Educating staff regarding safety science.
- Identification of potential hazards to inform subsequent care [161].
- Learning from previous problems [51]. Rather than employing a work-around or a "band aid," solution, clinicians design system interventions that reduce harm to future patients [48]. The following questions are asked and answered regarding each near-miss or actual adverse event:
  - What happened?
  - Why did it happen?
  - What can we do to reduce this risk?
  - How do we prove that we reduced this risk?
- Implementing tools to improve teamwork, communication, and the safety culture [51]. Tools include briefings, debriefings, and incident reporting. (See 'Briefings' above and 'Debriefings' above and 'Incident reporting' above.)
- Partnering with a hospital executive to support local efforts, provide needed resources, hold the team accountable, and inform senior leadership of safety hazards to patients.
- Ongoing measurement, feedback, and improvement. CUSP teams meet regularly to review safety issues, investigate newly identified defects, and design safer systems of care. An example is continual evaluation of failure to rescue events (defined as death of a patient

after one or more potentially treatable complications), which have been identified as an important surgical quality indicator [168].

SOCIETY GUIDELINE LINKS

Links to society and government-sponsored guidelines from selected countries and regions around the world are provided separately. (See "Society guideline links: Patient safety in the operating room".)

SUMMARY AND RECOMMENDATIONS

- **Human errors –** Individual human errors in the operating room (OR) include (see 'Human error: Types and prevention' above):
  - **Action-based (ie, skill) errors –** Prevention includes implementing known safety precautions, standardizing techniques, and building redundancy into systems (eg, two-person checks).
  - **Decision-based (ie, judgment or knowledge) errors –** Prevention includes use of cognitive aids, simulation training to practice decision-making during crises, and implementation of evidence-based best practices.
  - **Technical errors –** Prevention includes standardizing techniques, using technology such as ultrasound, or consulting with another provider with additional proficiency or expertise.
  - **Communication-based failures –** Prevention includes preoperative briefings, use of structured communication, and teamwork training to improve communication skills.
- **Approaches to risk reduction –** General approaches to risk reduction in the OR include (see 'General approaches to risk reduction' above):
  - **Review of informed consent –** Review the informed consent in the preoperative area and again before surgical incision (or regional block placement), including checks of patient identity (using dual identifiers), procedure to be performed, and the site, side, or level of the procedure (table 1). (See 'Reviews of informed consent' above and 'Timeouts' above.)
  - **Checklists and briefings –** Examples include:

- The anesthesia machine checkout is performed by the anesthesia provider (table 6).

- We suggest use of a preoperative checklist, such as the World Health Organization (WHO]) checklist (table 2) (**Grade 2C**), ideally with a surgeon-led briefing and participation of the entire OR team (eg, surgeon, anesthesiologist, circulating nurse, scrub technician). This includes team introductions; checking patient identity and verifying the intended procedure and site; discussing antibiotic administration and deep venous thrombosis prophylaxis (table 4 and table 5); verifying blood product availability; determining appropriate monitoring strategies; verifying availability of surgical equipment, instruments, and implants; planning appropriate patient positioning; ensuring team understanding of procedural goals and critical steps; planning postoperative disposition; and inviting team members to voice concerns or questions.

- If a central venous catheter is inserted, a checklist is used to ensure adherence to standard guidelines that prevent catheter-related bloodstream infection (table 7). (See 'Checklists' above and 'Briefings' above.)

- **Techniques to minimize distractions –** Attempt to minimize distractions (eg, limiting extraneous personnel in the OR, surgical interruptions, noise level due to alarms, conversations, beepers, and music). (See 'Techniques to minimize distractions and disruptions' above.)

- **Structure communication –** Use structured communication, particularly during complex surgical cases or crisis situations. (See 'Structured communication' above.)

- **Debriefings and handoffs –** Use a debriefing to identify hazards and suggest improvements after the procedure, and a formal handoff process during transition of care. (See 'Debriefings' above and "Handoffs of surgical patients".)

- **Risk reduction strategies –** Preventable hazards for patients in the OR may result in an adverse event. These include performance of the wrong surgical procedure or on the wrong site, infection of the bloodstream or surgical site, sharp object or needlestick injury, administration of the wrong medication or dose, equipment malfunction, positioning injuries, eye injury, retention of surgical items within the wound, and accidental awareness during general anesthesia. Other preventable physical hazards for both patient and OR personnel include fires and electrical or radiation injury (algorithm 3 and algorithm 4). (See 'Risk reduction strategies for specific hazards' above.)

- **Institutional approaches –** Institutional approaches to improve patient safety include implementing evidence-based best practices, team training, simulation training, incident reporting, and establishing a safety culture. (See 'Institutional approaches to safety improvement' above.)

REFERENCES

1. Methangkool E, Cole DJ, Cannesson M. Progress in Patient Safety in Anesthesia. JAMA 2020; 324:2485.
2. Suliburk JW, Buck QM, Pirko CJ, et al. Analysis of Human Performance Deficiencies Associated With Surgical Adverse Events. JAMA Netw Open 2019; 2:e198067.
3. Gawande AA, Thomas EJ, Zinner MJ, Brennan TA. The incidence and nature of surgical adverse events in Colorado and Utah in 1992. Surgery 1999; 126:66.
4. Kohn, LT, Corrigan, JM, Donaldson, MS, Eds; Committee on Quality of Health Care in America, Institute of Medicine. To Err Is Human: Building a Safer Health System. Washington, DC: National Academy Press; 1999.
5. Carayon P, Schoofs Hundt A, Karsh BT, et al. Work system design for patient safety: the SEIPS model. Qual Saf Health Care 2006; 15 Suppl 1:i50.
6. Marshall SD, Touzell A. Human factors and the safety of surgical and anaesthetic care. Anaesthesia 2020; 75 Suppl 1:e34.
7. Reason J. Human Error, Cambridge University, New York, NY 1990.
8. Kahneman D. Thinking, Fast and Slow, Penguin, London 2013.
9. Reason J. The Human Contribution: Unsafe Acts, Accidents and Heroic Recoveries, Ashgate Publishing Company, Burlington 2008.
10. Alper SJ, Karsh BT. A systematic review of safety violations in industry. Accid Anal Prev 2009; 41:739.
11. Merry A, Wahr J. Errors in the Context of Medication Administration. In: Medication Safety during Anesthesia and the Preoperative Period, Cambridge University, Cambridge p.I-Ii.
12. Kahneman D. Thinking, fast and slow, Farrar, Straus and Giroux, New York 2011. p.499.
13. Stanovich KE, West RF. Individual differences in reasoning: implications for the rationality debate? Behav Brain Sci 2000; 23:645.

14. Stiegler MP, Neelankavil JP, Canales C, Dhillon A. Cognitive errors detected in anaesthesiology: a literature review and pilot study. Br J Anaesth 2012; 108:229.
15. Neuhaus C, Huck M, Hofmann G, et al. Applying the human factors analysis and classification system to critical incident reports in anaesthesiology. Acta Anaesthesiol Scand 2018; 62:1403.
16. Stiegler MP, Tung A. Cognitive processes in anesthesiology decision making. Anesthesiology 2014; 120:204.
17. Croskerry P. The importance of cognitive errors in diagnosis and strategies to minimize them. Acad Med 2003; 78:775.
18. Neily J, Mills PD, Eldridge N, et al. Incorrect surgical procedures within and outside of the operating room. Arch Surg 2009; 144:1028.
19. Arriaga AF, Elbardissi AW, Regenbogen SE, et al. A policy-based intervention for the reduction of communication breakdowns in inpatient surgical care: results from a Harvard surgical safety collaborative. Ann Surg 2011; 253:849.
20. Greenberg CC, Regenbogen SE, Studdert DM, et al. Patterns of communication breakdowns resulting in injury to surgical patients. J Am Coll Surg 2007; 204:533.
21. Lingard L, Espin S, Whyte S, et al. Communication failures in the operating room: an observational classification of recurrent types and effects. Qual Saf Health Care 2004; 13:330.
22. Wauben LS, Dekker-van Doorn CM, van Wijngaarden JD, et al. Discrepant perceptions of communication, teamwork and situation awareness among surgical team members. Int J Qual Health Care 2011; 23:159.
23. Halverson AL, Casey JT, Andersson J, et al. Communication failure in the operating room. Surgery 2011; 149:305.
24. Nagpal K, Vats A, Ahmed K, et al. A systematic quantitative assessment of risks associated with poor communication in surgical care. Arch Surg 2010; 145:582.
25. Gillespie BM, Chaboyer W, Murray P. Enhancing communication in surgery through team training interventions: a systematic literature review. AORN J 2010; 92:642.
26. Dayton E, Henriksen K. Communication failure: basic components, contributing factors, and the call for structure. Jt Comm J Qual Patient Saf 2007; 33:34.
27. Hickson GB, Jenkins AD. Identifying and addressing communication failures as a means of reducing unnecessary malpractice claims. N C Med J 2007; 68:362.
28. Edmondson AC. Speaking up in the operating room: How team leaders promote learning in interdisciplinary action teams. J Manage Stud 2003; 40:1419.

29. Aggarwal R, Undre S, Moorthy K, et al. The simulated operating theatre: comprehensive training for surgical teams. Qual Saf Health Care 2004; 13 Suppl 1:i27.
30. Bruppacher HR, Alam SK, LeBlanc VR, et al. Simulation-based training improves physicians' performance in patient care in high-stakes clinical setting of cardiac surgery. Anesthesiology 2010; 112:985.
31. Blum RH, Raemer DB, Carroll JS, et al. A method for measuring the effectiveness of simulation-based team training for improving communication skills. Anesth Analg 2005; 100:1375.
32. Armour Forse R, Bramble JD, McQuillan R. Team training can improve operating room performance. Surgery 2011; 150:771.
33. Falcone RA Jr, Daugherty M, Schweer L, et al. Multidisciplinary pediatric trauma team training using high-fidelity trauma simulation. J Pediatr Surg 2008; 43:1065.
34. Healey AN, Undre S, Vincent CA. Defining the technical skills of teamwork in surgery. Qual Saf Health Care 2006; 15:231.
35. Manser T. Teamwork and patient safety in dynamic domains of healthcare: a review of the literature. Acta Anaesthesiol Scand 2009; 53:143.
36. McCulloch P, Mishra A, Handa A, et al. The effects of aviation-style non-technical skills training on technical performance and outcome in the operating theatre. Qual Saf Health Care 2009; 18:109.
37. Catchpole KR, Dale TJ, Hirst DG, et al. A multicenter trial of aviation-style training for surgical teams. J Patient Saf 2010; 6:180.
38. Alonso A, Baker DP, Holtzman A, et al. Reducing medical error in the Military Health System: How can team training help? Human Resource Management Review 2006; 16:396.
39. Tylee MJ, Rubenfeld GD, Wijeysundera D, et al. Anesthesiologist to Patient Communication: A Systematic Review. JAMA Netw Open 2020; 3:e2023503.
40. Hudson ME, Chelly JE, Lichter JR. Wrong-site nerve blocks: 10 yr experience in a large multihospital health-care system. Br J Anaesth 2015; 114:818.
41. Barrington MJ, Uda Y, Pattullo SJ, Sites BD. Wrong-site regional anesthesia: review and recommendations for prevention? Curr Opin Anaesthesiol 2015; 28:670.
42. Cohen SP, Hayek SM, Datta S, et al. Incidence and root cause analysis of wrong-site pain management procedures: a multicenter study. Anesthesiology 2010; 112:711.
43. Freundlich RE, Bulka CM, Wanderer JP, et al. Prospective Investigation of the Operating Room Time-Out Process. Anesth Analg 2020; 130:725.

44. Ali M, Osborne A, Bethune R, Pullyblank A. Preoperative surgical briefings do not delay operating room start times and are popular with surgical team members. J Patient Saf 2011; 7:139.
45. Allard J, Bleakley A, Hobbs A, Coombes L. Pre-surgery briefings and safety climate in the operating theatre. BMJ Qual Saf 2011; 20:711.
46. Bethune R, Sasirekha G, Sahu A, et al. Use of briefings and debriefings as a tool in improving team work, efficiency, and communication in the operating theatre. Postgrad Med J 2011; 87:331.
47. Lingard L, Regehr G, Cartmill C, et al. Evaluation of a preoperative team briefing: a new communication routine results in improved clinical practice. BMJ Qual Saf 2011; 20:475.
48. Papaspyros SC, Javangula KC, Adluri RK, O'Regan DJ. Briefing and debriefing in the cardiac operating room. Analysis of impact on theatre team attitude and patient safety. Interact Cardiovasc Thorac Surg 2010; 10:43.
49. Paull DE, Mazzia LM, Wood SD, et al. Briefing guide study: preoperative briefing and postoperative debriefing checklists in the Veterans Health Administration medical team training program. Am J Surg 2010; 200:620.
50. Markin NW. Navigating to the Goal: The Importance of Shared Mental Models in Complex Environments. J Cardiothorac Vasc Anesth 2018; 32:2618.
51. Cooper JB. Critical Role of the Surgeon-Anesthesiologist Relationship for Patient Safety. Anesthesiology 2018; 129:402.
52. Neily J, Mills PD, Young-Xu Y, et al. Association between implementation of a medical team training program and surgical mortality. JAMA 2010; 304:1693.
53. Altpeter T, Luckhardt K, Lewis JN, et al. Expanded surgical time out: a key to real-time data collection and quality improvement. J Am Coll Surg 2007; 204:527.
54. Weiser TG, Haynes AB. Ten years of the Surgical Safety Checklist. Br J Surg 2018; 105:927.
55. Abbott TEF, Ahmad T, Phull MK, et al. The surgical safety checklist and patient outcomes after surgery: a prospective observational cohort study, systematic review and meta-analysis. Br J Anaesth 2018; 120:146.
56. Bergs J, Hellings J, Cleemput I, et al. Systematic review and meta-analysis of the effect of the World Health Organization surgical safety checklist on postoperative complications. Br J Surg 2014; 101:150.
57. Gillespie BM, Chaboyer W, Thalib L, et al. Effect of using a safety checklist on patient complications after surgery: a systematic review and meta-analysis. Anesthesiology 2014; 120:1380.

58. Bosk CL, Dixon-Woods M, Goeschel CA, Pronovost PJ. Reality check for checklists. Lancet 2009; 374:444.
59. Leape LL. The checklist conundrum. N Engl J Med 2014; 370:1063.
60. Burian BK, Clebone A, Dismukes K, Ruskin KJ. More Than a Tick Box: Medical Checklist Development, Design, and Use. Anesth Analg 2018; 126:223.
61. van Klei WA, Hoff RG, van Aarnhem EE, et al. Effects of the introduction of the WHO "Surgical Safety Checklist" on in-hospital mortality: a cohort study. Ann Surg 2012; 255:44.
62. Jelacic S, Bowdle A, Nair BG, et al. Aviation-Style Computerized Surgical Safety Checklist Displayed on a Large Screen and Operated by the Anesthesia Provider Improves Checklist Performance. Anesth Analg 2020; 130:382.
63. Healey AN, Sevdalis N, Vincent CA. Measuring intra-operative interference from distraction and interruption observed in the operating theatre. Ergonomics 2006; 49:589.
64. Wiegmann DA, ElBardissi AW, Dearani JA, et al. Disruptions in surgical flow and their relationship to surgical errors: an exploratory investigation. Surgery 2007; 142:658.
65. Schmid F, Goepfert MS, Kuhnt D, et al. The wolf is crying in the operating room: patient monitor and anesthesia workstation alarming patterns during cardiac surgery. Anesth Analg 2011; 112:78.
66. Fritsch MH, Chacko CE, Patterson EB. Operating room sound level hazards for patients and physicians. Otol Neurotol 2010; 31:715.
67. Panahi P, Stroh M, Casper DS, et al. Operating room traffic is a major concern during total joint arthroplasty. Clin Orthop Relat Res 2012; 470:2690.
68. Young RS, O'Regan DJ. Cardiac surgical theatre traffic: time for traffic calming measures? Interact Cardiovasc Thorac Surg 2010; 10:526.
69. Cesarano FL, Piergeorge AR. The Spaghetti Syndrome. A new clinical entity. Crit Care Med 1979; 7:182.
70. Carthey J, de Leval MR, Reason JT. The human factor in cardiac surgery: errors and near misses in a high technology medical domain. Ann Thorac Surg 2001; 72:300.
71. de Leval MR. Human factors and outcomes of cardiac surgery. Paediatr Anaesth 1996; 6:349.
72. ElBardissi AW, Wiegmann DA, Henrickson S, et al. Identifying methods to improve heart surgery: an operative approach and strategy for implementation on an organizational level. Eur J Cardiothorac Surg 2008; 34:1027.
73. Catchpole KR, Giddings AE, Wilkinson M, et al. Improving patient safety by identifying latent failures in successful operations. Surgery 2007; 142:102.

74. Solis-Trapala IL, Carthey J, Farewell VT, de Leval MR. Dynamic modelling in a study of surgical error management. Stat Med 2007; 26:5189.
75. Lynch RJ, Englesbe MJ, Sturm L, et al. Measurement of foot traffic in the operating room: implications for infection control. Am J Med Qual 2009; 24:45.
76. Wadhera RK, Parker SH, Burkhart HM, et al. Is the "sterile cockpit" concept applicable to cardiovascular surgery critical intervals or critical events? The impact of protocol-driven communication during cardiopulmonary bypass. J Thorac Cardiovasc Surg 2010; 139:312.
77. Paterson E, Sanderson PM, Brecknell B, et al. Comparison of Standard and Enhanced Pulse Oximeter Auditory Displays of Oxygen Saturation: A Laboratory Study With Clinician and Nonclinician Participants. Anesth Analg 2019; 129:997.
78. Lingard L, Reznick R, Espin S, et al. Team communications in the operating room: talk patterns, sites of tension, and implications for novices. Acad Med 2002; 77:232.
79. Salas E, Wilson KA, Murphy CE, et al. Communicating, coordinating, and cooperating when lives depend on it: tips for teamwork. Jt Comm J Qual Patient Saf 2008; 34:333.
80. Santos R, Bakero L, Franco P, et al. Characterization of non-technical skills in paediatric cardiac surgery: communication patterns. Eur J Cardiothorac Surg 2012; 41:1005.
81. Hazlehurst B, McMullen CK, Gorman PN. Distributed cognition in the heart room: how situation awareness arises from coordinated communications during cardiac surgery. J Biomed Inform 2007; 40:539.
82. Berenholtz SM, Schumacher K, Hayanga AJ, et al. Implementing standardized operating room briefings and debriefings at a large regional medical center. Jt Comm J Qual Patient Saf 2009; 35:391.
83. McGreevy JM, Otten TD. Briefing and debriefing in the operating room using fighter pilot crew resource management. J Am Coll Surg 2007; 205:169.
84. Salas E, Klein C, King H, et al. Debriefing medical teams: 12 evidence-based best practices and tips. Jt Comm J Qual Patient Saf 2008; 34:518.
85. Devine J, Chutkan N, Norvell DC, Dettori JR. Avoiding wrong site surgery: a systematic review. Spine (Phila Pa 1976) 2010; 35:S28.
86. Deutsch ES, Yonash RA, Martin DE, et al. Wrong-site nerve blocks: A systematic literature review to guide principles for prevention. J Clin Anesth 2018; 46:101.
87. The Joint Commission. Summary data of sentinel events reviewed by The Joint Commission. https://www.jointcommission.org/assets/1/18/Summary_2Q_2016.pdf (Accessed on December 07, 2016).

88. Hempel S, Maggard-Gibbons M, Nguyen DK, et al. Wrong-Site Surgery, Retained Surgical Items, and Surgical Fires : A Systematic Review of Surgical Never Events. JAMA Surg 2015; 150:796.
89. Hopping M, Merry AF, Pandit JJ. Exploring performance of, and attitudes to, Stop- and Mock-Before-You-Block in preventing wrong-side blocks. Anaesthesia 2018; 73:421.
90. Chikkabbaiah V, French J, Townsley P, Bedforth N. Further reducing the risk of wrong site block. Anaesthesia 2015; 70:1453.
91. Moppett IK, Shorrock ST. Working out wrong-side blocks. Anaesthesia 2018; 73:407.
92. Tanner J, Padley W, Assadian O, et al. Do surgical care bundles reduce the risk of surgical site infections in patients undergoing colorectal surgery? A systematic review and cohort meta-analysis of 8,515 patients. Surgery 2015; 158:66.
93. Mauermann WJ, Nemergut EC. The anesthesiologist's role in the prevention of surgical site infections. Anesthesiology 2006; 105:413.
94. Munoz-Price LS, Bowdle A, Johnston BL, et al. Infection prevention in the operating room anesthesia work area. Infect Control Hosp Epidemiol 2019; 40:1.
95. Munoz-Price LS, Lubarsky DA, Arheart KL, et al. Interactions between anesthesiologists and the environment while providing anesthesia care in the operating room. Am J Infect Control 2013; 41:922.
96. Noble RMN, Salim SY, Walker B, et al. Survival of Staphylococcus epidermidis in Propofol and Intralipid in the Dead Space of Intravenous Injection Ports. Anesth Analg 2019; 129:e20.
97. Baronos S, Yarmush JM, Stedman JL, et al. Normal Saline and Dextrose 5% in Water Do Not Support Bacterial Growth 24 Hours After Being Spiked in the Perioperative Environment. Anesth Analg 2019; 128:1185.
98. Loftus RW, Koff MD, Birnbach DJ. The dynamics and implications of bacterial transmission events arising from the anesthesia work area. Anesth Analg 2015; 120:853.
99. Loftus RW, Brown JR, Patel HM, et al. Transmission dynamics of gram-negative bacterial pathogens in the anesthesia work area. Anesth Analg 2015; 120:819.
100. Birnbach DJ, Rosen LF, Fitzpatrick M, et al. Double gloves: a randomized trial to evaluate a simple strategy to reduce contamination in the operating room. Anesth Analg 2015; 120:848.
101. Seamon MJ, Wobb J, Gaughan JP, et al. The effects of intraoperative hypothermia on surgical site infection: an analysis of 524 trauma laparotomies. Ann Surg 2012; 255:789.
102. Sessler DI. New surgical thermal management guidelines. Lancet 2009; 374:1049.

103. Sessler DI. Perioperative thermoregulation and heat balance. Lancet 2016; 387:2655.
104. John M, Ford J, Harper M. Peri-operative warming devices: performance and clinical application. Anaesthesia 2014; 69:623.
105. Perl T, Bräuer A, Quintel M. Prevention of perioperative hypothermia with forced-air warming systems and upper-body blankets. Surg Technol Int 2006; 15:19.
106. Madrid E, Urrútia G, Roqué i Figuls M, et al. Active body surface warming systems for preventing complications caused by inadvertent perioperative hypothermia in adults. Cochrane Database Syst Rev 2016; 4:CD009016.
107. Gandhi GY, Murad MH, Flynn DN, et al. Effect of perioperative insulin infusion on surgical morbidity and mortality: systematic review and meta-analysis of randomized trials.7. Mayo Clin Proc 2008; 83:418.
108. Mattishent K, Thavarajah M, Sinha A, et al. Safety of 80% vs 30-35% fraction of inspired oxygen in patients undergoing surgery: a systematic review and meta-analysis. Br J Anaesth 2019; 122:311.
109. Berríos-Torres SI, Umscheid CA, Bratzler DW, et al. Centers for Disease Control and Prevention Guideline for the Prevention of Surgical Site Infection, 2017. JAMA Surg 2017; 152:784.
110. de Jonge S, Egger M, Latif A, et al. Effectiveness of 80% vs 30-35% fraction of inspired oxygen in patients undergoing surgery: an updated systematic review and meta-analysis. Br J Anaesth 2019; 122:325.
111. Myles PS, Carlisle JB, Scarr B. Evidence for compromised data integrity in studies of liberal peri-operative inspired oxygen. Anaesthesia 2019; 74:573.
112. Chu DK, Kim LH, Young PJ, et al. Mortality and morbidity in acutely ill adults treated with liberal versus conservative oxygen therapy (IOTA): a systematic review and meta-analysis. Lancet 2018; 391:1693.
113. Beers RA. Infectious disease risks for anesthesiologists. ASA Monitor 2019; 83:8.
114. Perioperative considerations for the 2019 Novel Coronavirus (Covid-19). Anesthesia Patient s Safety Foundation Newsletter; February 2020. https://www.apsf.org/news-updates/perioperative-considerations-for-the-2019-novel-coronavirus-covid-19/ (Accessed on March 17, 2020).
115. Donning and doffing personal protective equipment. Centers for Disease Control and Prevention. https://www.cdc.gov/hai/pdfs/ppe/PPE-Sequence.pdf (Accessed on March 24, 2020).
116. American Society of Anesthesiologists UPDATE: The Use of Personal Protective Equipment by Anesthesia Professionals during the COVID-19 Pandemic https://www.asahq.org/about-as

a/newsroom/news-releases/2020/03/update-the-use-of-personal-protective-equipment-by-anesthesia-professionals-during-the-covid-19-pandemic (Accessed on March 24, 2020).

117. Martinez EA, Thompson DA, Errett NA, et al. Review article: high stakes and high risk: a focused qualitative review of hazards during cardiac surgery. Anesth Analg 2011; 112:1061.
118. Pennathur PR, Thompson D, Abernathy JH 3rd, et al. Technologies in the wild (TiW): human factors implications for patient safety in the cardiovascular operating room. Ergonomics 2013; 56:205.
119. Martinez EA, Shore A, Colantuoni E, et al. Cardiac surgery errors: results from the UK National Reporting and Learning System. Int J Qual Health Care 2011; 23:151.
120. Wiegmann D, Suther T, Neal J, et al. A human factors analysis of cardiopulmonary bypass machines. J Extra Corpor Technol 2009; 41:57.
121. Leotsakos A, Zheng H, Croteau R, et al. Standardization in patient safety: the WHO High 5s project. Int J Qual Health Care 2014; 26:109.
122. Lorraway PG, Savoldelli GL, Joo HS, et al. Management of simulated oxygen supply failure: is there a gap in the curriculum? Anesth Analg 2006; 102:865.
123. Chrimes N, Bradley WPL, Gatward JJ, Weatherall AD. Human factors and the 'next generation' airway trolley. Anaesthesia 2019; 74:427.
124. https://www.asahq.org/For-Members/Clinical-Information/2008-ASA-Recommendations-for-PreAnesthesia-Checkout.aspx.
125. Park S, Ahn JY, Ahn YE, et al. Two Cases of Cerebral Air Embolism That Occurred during Esophageal Ballooning and Endoscopic Retrograde Cholangiopancreatography. Clin Endosc 2016; 49:191.
126. Barker SJ, Doyle DJ. Electrical safety in the operating room: dry versus wet. Anesth Analg 2010; 110:1517.
127. Srejic U, Larson P, Bickler PE. Little Black Boxes: Noncardiac Implantable Electronic Medical Devices and Their Anesthetic and Surgical Implications. Anesth Analg 2017; 125:124.
128. The Joint Commision. National patient safety gaols effective January 1, 2015. http://www.jointcommission.org/assets/1/6/2015_NPSG_HAP.pdf (Accessed on December 19, 2016).
129. Consensus report, Institute of Medicine. Clinical practice guidelines we can trust. March 23, 2011. http://www.iom.edu/Reports/2011/Clinical-Practice-Guidelines-We-Can-Trust.aspx (Accessed on January 13, 2012).
130. Sun E, Mello MM, Rishel CA, et al. Association of Overlapping Surgery With Perioperative Outcomes. JAMA 2019; 321:762.

131. Lugtenberg M, Zegers-van Schaick JM, Westert GP, Burgers JS. Why don't physicians adhere to guideline recommendations in practice? An analysis of barriers among Dutch general practitioners. Implement Sci 2009; 4:54.

132. Institute of Medicine. Standards for Developing Trustworthy Clinical Practice Guidelines. http://iom.edu/Activities/Quality/ClinicPracGuide.aspx (Accessed on July 05, 2011).

133. Carney BT, West P, Neily J, et al. Changing perceptions of safety climate in the operating room with the Veterans Health Administration medical team training program. Am J Med Qual 2011; 26:181.

134. Dunn EJ, Mills PD, Neily J, et al. Medical team training: applying crew resource management in the Veterans Health Administration. Jt Comm J Qual Patient Saf 2007; 33:317.

135. Higham H, Baxendale B. To err is human: use of simulation to enhance training and patient safety in anaesthesia. Br J Anaesth 2017; 119:i106.

136. Weller JM, Merry AF, Robinson BJ, et al. The impact of trained assistance on error rates in anaesthesia: a simulation-based randomised controlled trial. Anaesthesia 2009; 64:126.

137. Ziewacz JE, Arriaga AF, Bader AM, et al. Crisis checklists for the operating room: development and pilot testing. J Am Coll Surg 2011; 213:212.

138. Stevens LM, Cooper JB, Raemer DB, et al. Educational program in crisis management for cardiac surgery teams including high realism simulation. J Thorac Cardiovasc Surg 2012; 144:17.

139. Arriaga AF, Bader AM, Wong JM, et al. Simulation-based trial of surgical-crisis checklists. N Engl J Med 2013; 368:246.

140. Manser T, Harrison TK, Gaba DM, Howard SK. Coordination patterns related to high clinical performance in a simulated anesthetic crisis. Anesth Analg 2009; 108:1606.

141. Moorthy K, Munz Y, Forrest D, et al. Surgical crisis management skills training and assessment: a simulation[corrected]-based approach to enhancing operating room performance. Ann Surg 2006; 244:139.

142. Powers KA, Rehrig ST, Irias N, et al. Simulated laparoscopic operating room crisis: An approach to enhance the surgical team performance. Surg Endosc 2008; 22:885.

143. Evain JN, Perrot A, Vincent A, et al. Team planning discussion and clinical performance: a prospective, randomised, controlled simulation trial. Anaesthesia 2019; 74:488.

144. Weinger MB, Banerjee A, Burden AR, et al. Simulation-based Assessment of the Management of Critical Events by Board-certified Anesthesiologists. Anesthesiology 2017; 127:475.

145. Wetzel CM, Black SA, Hanna GB, et al. The effects of stress and coping on surgical performance during simulations. Ann Surg 2010; 251:171.
146. Arora S, Sevdalis N, Nestel D, et al. Managing intraoperative stress: what do surgeons want from a crisis training program? Am J Surg 2009; 197:537.
147. Aggarwal R, Mishra A, Crochet P, et al. Effect of caffeine and taurine on simulated laparoscopy performed following sleep deprivation. Br J Surg 2011; 98:1666.
148. McClelland L, Plunkett E, McCrossan R, et al. A national survey of out-of-hours working and fatigue in consultants in anaesthesia and paediatric intensive care in the UK and Ireland. Anaesthesia 2019; 74:1509.
149. Yang N, Elmatite WM, Elgallad A, et al. Patient outcomes related to the daytime versus after-hours surgery: A meta-analysis. J Clin Anesth 2019; 54:13.
150. Darling E, Searles B. Oxygenator change-out times: the value of a written protocol and simulation exercises. Perfusion 2010; 25:141.
151. Depriest JL, Patil R, Patil T. The Code Blue 2-min drill. Resuscitation 2010; 81:140.
152. Kurup V, Matei V, Ray J. Role of in-situ simulation for training in healthcare: opportunities and challenges. Curr Opin Anaesthesiol 2017; 30:755.
153. Cohen JB, Patel SY. Getting to Zero Patient Harm: From Improving Our Existing Tools to Embracing a New Paradigm. Anesth Analg 2020; 130:547.
154. Lee LA, Domino KB. The Closed Claims Project. Has it influenced anesthetic practice and outcome? Anesthesiol Clin North America 2002; 20:485.
155. Dutton RP. Introducing the Anesthesia Incident Reporting System (AIRS). Newsl Am Soc Anesthesiol 2011; 75:30.
156. Scott Beattie W, Culwick MD, Grocott HP. Canadian Anesthesia Incident Reporting System (CAIRS): The Canadian Anesthesiologists' Society's National Patient Safety Initiative. Can J Anaesth 2018; 65:749.
157. Gibbs NM, Culwick M, Merry AF. A cross-sectional overview of the first 4,000 incidents reported to webAIRS, a de-identified web-based anaesthesia incident reporting system in Australia and New Zealand. Anaesth Intensive Care 2017; 45:28.
158. Wanderer JP, Gratch DM, Jacques PS, et al. Trends in the Prevalence of Intraoperative Adverse Events at Two Academic Hospitals After Implementation of a Mandatory Reporting System. Anesth Analg 2018; 126:134.
159. Andrzejczak C, Karwowski W, Thompson W. The identification of factors contributing to self-reported anomalies in civil aviation. Int J Occup Saf Ergon 2014; 20:3.

160. Liberman JS, Slagle JM, Whitney G, et al. Incidence and Classification of Nonroutine Events during Anesthesia Care. Anesthesiology 2020; 133:41.
161. Frankel AS, Leonard MW, Denham CR. Fair and just culture, team behavior, and leadership engagement: The tools to achieve high reliability. Health Serv Res 2006; 41:1690.
162. Albright-Trainer B, Dayal R, Agarwala A, Pukenas E. Effecgtive leadership and patient safety culture. APSF Newsletter 2020; (June):44.
163. Pronovost PJ, Holzmueller CG, Martinez E, et al. A practical tool to learn from defects in patient care. Jt Comm J Qual Patient Saf 2006; 32:102.
164. Smith AF, Plunkett E. People, systems and safety: resilience and excellence in healthcare practice. Anaesthesia 2019; 74:508.
165. Pronovost PJ, Berenholtz SM, Goeschel C, et al. Improving patient safety in intensive care units in Michigan. J Crit Care 2008; 23:207.
166. Pronovost P, Weast B, Rosenstein B. Implementing and validating a Comprehensive Unit-based Safety Program. J Patient Safety 2005; 1:33.
167. Timmel J, Kent PS, Holzmueller CG, et al. Impact of the Comprehensive Unit-based Safety Program (CUSP) on safety culture in a surgical inpatient unit. Jt Comm J Qual Patient Saf 2010; 36:252.
168. Portuondo JI, Shah SR, Singh H, Massarweh NN. Failure to Rescue as a Surgical Quality Indicator: Current Concepts and Future Directions for Improving Surgical Outcomes. Anesthesiology 2019; 131:426.

Topic 15077 Version 51.0

GRAPHICS

JCAHO protocol for surgical timeout

1. Perform a preoperative verification process (ideally with the patient awake, aware and involved)
Ensure that all relevant documents and studies are available prior to the start of the procedure. Identify the patient with at least two patient identifiers (eg, name, number, telephone number).
Ensure that this information has been reviewed and is internally consistent as well as consistent with the patient's expectations and with the surgical team's understanding of the intended patient, procedure, site and, as applicable, any implants.
Missing information or discrepancies must be addressed before starting surgery.
2. Mark the operative site to unambiguously identify the intended procedure site
For procedures involving right/left distinction, multiple structures (such as fingers and toes), or multiple levels (as in spinal procedures), the intended site must be marked. Ideally the surgeon in charge will mark the site. A procedure must be defined for patients who refuse site marking.
The mark must be unambiguous (eg, use initials or "YES" or a line representing the planned incision; "X" may be ambiguous). The mark must be visible after the patient has been prepped and draped (eg, use a permanent marker). Nonoperative sites should not be marked.
3. The entire operating team takes a "time out" immediately before starting the procedure to conduct a final verification of the correct patient, procedure, site and, as applicable, implants.
The procedure is not started until any questions or concerns are resolved and all members of the surgical/procedure team are in agreement. Identify the patient with at least two patient identifiers.

Adapted from the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) at www.jcaho.org/index.htm.

Graphic 59666 Version 2.0

World Health Organization surgical safety checklist

Sign in	
Before induction of anesthesia	
__	Patient has confirmed: ▪ Identity ▪ Site ▪ Procedure ▪ Consent
__	Site marked/not applicable
__	Anesthesia safety check completed
__	Pulse oximeter on patient and functioning
Does patient have a:	
Known allergy?	
__	No
__	Yes
Difficult airway/aspiration risk?	
__	No
__	Yes, and equipment/assistance available
Risk of >500 mL blood loss (7 mL/kg in children)?	
__	No
__	Yes, and adequate intravenous access and fluids planned

Time out	
Before skin incision	
__	Confirm all team members have introduced themselves by name and role
__	Surgeon, anesthesia professional, and nurse verbally confirm ▪ Patient ▪ Site ▪ Procedure
Anticipated critical events	
__	Surgeon reviews: What are the critical or unexpected steps, operative duration, anticipated blood loss?
__	Anesthesia team reviews: Are there any patient-specific concerns?
__	Nursing team reviews: Has sterility (including indicator results) been confirmed? Are there equipment issues or any concerns?
Has antibiotic prophylaxis been given within the last 60 minutes?	
__	Yes
__	Not applicable
Is essential imaging displayed?	
__	Yes
__	Not applicable

Sign out	
Before patient leaves operating room	
Nurse verbally confirms with the team:	
__	The name of the procedure recorded
__	That instrument, sponge, and needle counts are correct (or not applicable)
__	How the specimen is labeled (including patient name)
__	Whether there are any equipment problems to be addressed
__	Surgeon, anesthesia professional, and nurse review the key concerns for recovery and management of this patient

This checklist is not intended to be comprehensive. Additions and modifications to fit local practice are encouraged.

Graphic 52392 Version 12.0

American Society of Anesthesiologists Physical Status (ASA PS) Classification System

ASA PS classification	Definition	Examples, including, but not limited to:
ASA I	A normal healthy patient	Healthy, nonsmoking, no or minimal alcohol use.
ASA II	A patient with mild systemic disease	Mild diseases only without substantive functional limitations. Current smoker, social alcohol drinker, pregnancy, obesity (30<BMI<40), well-controlled DM/HTN, mild lung disease.
ASA III	A patient with severe systemic disease	Substantive functional limitations; one or more moderate to severe diseases. Poorly controlled DM or HTN, COPD, morbid obesity (BMI ≥40), active hepatitis, alcohol dependence or abuse, implanted pacemaker, moderate reduction of ejection fraction, ESKD undergoing regularly scheduled dialysis, premature infant PCA <60 weeks, history (>3 months) of MI, CVA, TIA, or CAD/stents.
ASA IV	A patient with severe systemic disease that is a constant threat to life	Recent (<3 months) MI, CVA, TIA, or CAD/stents, ongoing cardiac ischemia or severe valve dysfunction, severe reduction of ejection fraction, sepsis, DIC, ARDS, or ESKD not undergoing regularly scheduled dialysis.
ASA V	A moribund patient who is not expected to survive without the operation	Ruptured abdominal/thoracic aneurysm, massive trauma, intracranial bleed with mass effect, ischemic bowel in the face of significant cardiac pathology or multiple organ/system dysfunction.
ASA VI	A declared brain-dead patient whose organs are being removed for donor purposes	

The addition of "E" to the numerical status (eg, IE, IIE, etc) denotes Emergency surgery (an emergency is defined as existing when delay in treatment of the patient would lead to a significant increase in the threat to life or body part).

BMI: body mass index; DM: diabetes mellitus; HTN: hypertension; COPD: chronic obstructive pulmonary disease; ESKD: end-stage kidney disease; PCA: post conceptual age; MI: myocardial infarction; CVA: cerebrovascular accident; TIA: transient ischemic attack; CAD: coronary artery disease; DIC: disseminated intravascular coagulation; ARDS: acute respiratory distress syndrome.

Graphic 87504 Version 9.0

Timing of prophylactic antibiotic administration and subsequent rates of SSIs

Time of administration*	Percent with SSI	Odds ratio¶	95% CI
Early	3.8	4.3	1.8-10.4
Preoperative	0.6	1	-
Perioperative	1.4	2.1	0.6-7.4
Postoperative	3.3	5.8	2.4-13.8

SSI: surgical site infection.

* "Early" denotes 2 to 24 hours before incision, "preoperative" 0 to 2 hours before incision, "perioperative" within 3 hours after incision, and "postoperative" more than 3 hours after incision.

¶ Odds ratio determined by logistic-regression analysis.

Data from: Classen DC, Evans RS, Pestotnik SL, et al. The timing of prophylactic administration of antibiotics and the risk of surgical-wound infection. N Engl J Med 1992; 326:281.

Graphic 79097 Version 9.0

Modified Caprini risk assessment model for VTE in general surgical patients

Risk score			
1 point	**2 points**	**3 points**	**5 points**
Age 41 to 60 years	Age 61 to 74 years	Age ≥75 years	Stroke (<1 month)
Minor surgery	Arthroscopic surgery	History of VTE	Elective arthroplasty
BMI >25 kg/m^2	Major open surgery (>45 minutes)	Family history of VTE	Hip, pelvis, or leg fracture
Swollen legs	Laparoscopic surgery (>45 minutes)	Factor V Leiden	Acute spinal cord injury (<1 month)
Varicose veins	Malignancy	Prothrombin 20210A	
Pregnancy or postpartum	Confined to bed (>72 hours)	Lupus anticoagulant	
History of unexplained or recurrent spontaneous abortion	Immobilizing plaster cast	Anticardiolipin antibodies	
Oral contraceptives or hormone replacement	Central venous access	Elevated serum homocysteine	
Sepsis (<1 month)		Heparin-induced thrombocytopenia	
Serious lung disease, including pneumonia (<1 month)		Other congenital or acquired thrombophilia	
Abnormal pulmonary function			
Acute myocardial infarction			
Congestive heart failure (<1 month)			
History of inflammatory bowel disease			
Medical patient at bed rest			

Interpretation		
Surgical risk	**Score**	**Estimated VTE risk**

category*		**in the absence of pharmacologic or mechanical prophylaxis (percent)**
Very low (see text for definition)	0	<0.5
Low	1 to 2	1.5
Moderate	3 to 4	3.0
High	≥5	6.0

VTE: venous thromboembolism; BMI: body mass index.

* This table is applicable only to general, abdominal-pelvic, bariatric, vascular, and plastic and reconstructive surgery. See text for other types of surgery (eg, cancer surgery).

From: Gould MK, Garcia DA, Wren SM, et al. Prevention of VTE in nonorthopedic surgical patients: antithrombotic therapy and prevention of thrombosis, 9th ed: American College of Chest Physicians evidence-based clinical practical guidelines. Chest 2012; 141:e227S. Copyright © 2012. Reproduced with permission from the American College of Chest Physicians.

Graphic 83739 Version 14.0

American Society of Anesthesiologists Summary of Anesthesia Machine Checkout Recommendations

Item to be completed	Responsible party
To be completed daily	
Item #1: Verify that auxiliary oxygen cylinder and self-inflating manual ventilation device are available and functioning	Provider and technician
Item #2: Verify that patient suction is adequate to clear the airway	Provider and technician
Item #3: Turn on anesthesia delivery system and confirm that AC power is available	Provider or technician
Item #4: Verify availability of required monitors, including alarms	Provider or technician
Item #5: Verify that pressure is adequate on the spare oxygen cylinder mounted on the anesthesia machine	Provider and technician
Item #6: Verify that the piped gas pressures are ≥50 psig	Provider and technician
Item #7: Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed	Provider or technician
Item #8: Verify that there are no leaks in the gas supply lines between the flowmeters and the common gas outlet	Provider or technician
Item #9: Test scavenging system function	Provider or technician
Item #10: Calibrate, or verify calibration of, the oxygen monitor, and check the low oxygen alarm	Provider or technician
Item #11: Verify that carbon dioxide absorbent is not exhausted	Provider or technician
Item #12: Breathing system pressure and leak testing	Provider and technician
Item #13: Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and technician
Item #14: Document completion of checkout procedures	Provider and technician
Item #15: Confirm ventilator settings and evaluate readiness to deliver anesthesia care **(anesthesia time out)**	Provider
To be completed prior to each procedure	

Item #2: Verify that patient suction is adequate to clear the airway	Provider and technician
Item #4: Verify availability of required monitors, including alarms	Provider or technician
Item #7: Verify that vaporizers are adequately filled and, if applicable, that the filler ports are tightly closed	Provider
Item #11: Verify that carbon dioxide absorbent is not exhausted	Provider or technician
Item #12: Breathing system pressure and leak testing	Provider and technician
Item #13: Verify that gas flows properly through the breathing circuit during both inspiration and exhalation	Provider and technician
Item #14: Document completion of checkout procedures	Provider and technician
Item #15: Confirm ventilator settings and evaluate readiness to deliver anesthesia care **(anesthesia time out)**	Provider

AC: alternating current; psig: pounds per square inch gauge.

Reproduced with permission from: Riutort KT, Eisenkraft JB. The Anesthesia Workstation and Delivery Systems for Inhaled Anesthetics. In: Clinical Anesthesia, 7th ed, Barash PG, Cullen BF, Stoelting RK, et al. (Eds), Lippincott Williams & Wilkins, Philadelphia 2013. Copyright © 2013 Lippincott Williams & Wilkins. www.lww.com.

Graphic 101563 Version 6.0

General recommendations for prevention of infections associated with any intravascular catheter in adult and pediatric patients

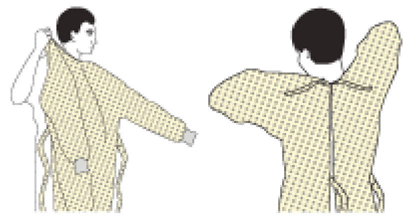
Health care worker education and training
Educate health care workers regarding indication for intravascular catheter use, proper procedures for insertion and maintenance, and infection control measures to prevent intravascular catheter-associated infections.
Hand hygiene
Observe proper hand hygiene either by washing hands with conventional antiseptic-containing soap and water or with waterless alcohol-based gels or foams. Use of gloves does not obviate the need for hand hygiene.
Aseptic technique during catheter insertion and care
Maintain aseptic technique for the insertion and care of intravascular catheters. Use maximal barrier precautions when inserting arterial or central venous catheters.
Catheter site care
Disinfect clean skin with an appropriate antiseptic before catheter insertion and at the time of dressing changes. A 2% chlorhexidine-based preparation is preferred, but there is no recommendation for its use in infants less than 2 months of age.
Use sterile gauze or sterile transparent semipermeable dressing to cover the catheter site.
Do not use topical antibiotic ointment or creams on insertion sites (except for dialysis catheters).
Replacement of intravascular catheters
Remove any intravascular catheter that is no longer essential.
Replacement of infusion sets
Replace administration sets (including secondary sets and add-on devices) every 7 days (in the absence of a clinical indication for earlier replacement). Replace tubing used to administer blood, blood products, or lipid emulsions within 24 hours of initiating the infusion. Replace tubing used to administer propofol infusions every 6 to 12 hours, depending on its use, per the manufacturer's recommendation.
Parenteral fluids
Complete the infusion of lipid-containing solutions within 24 hours of hanging the solution.
Complete the infusion of lipid emulsions alone within 12 hours of hanging the solution.
Complete infusions of blood or other blood products within 4 hours of hanging the blood.
Intravenous injection ports
Clean injection ports with 70% alcohol or an iodophor before accessing the system.

Graphic 75251 Version 6.0

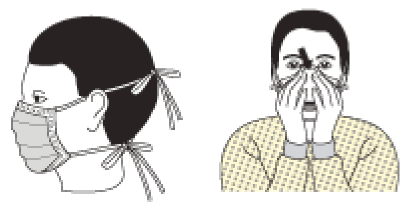
Putting on personal protective equipment

The type of PPE used will vary based on the level of precautions required, such as standard and contact, droplet or airborne infection isolation precautions. The procedure for putting on and removing PPE should be tailored to the specific type of PPE.

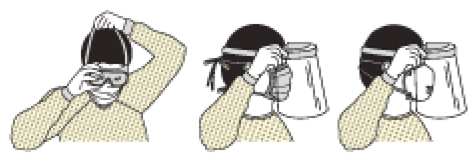
1. Gown
- Fully cover torso from neck to knees, arms to end of wrists, and wrap around the back.
- Fasten in back of neck and waist.



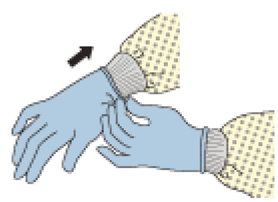
2. Mask or respirator
- Secure ties or elastic bands at middle of head and neck.
- Fit flexible band to nose bridge.
- Fit snug to face and below chin.
- Fit-check respirator.



3. Goggles or face shield
- Place over face and eyes and adjust to fit.



4. Gloves
- Extend to cover wrist of isolation gown.



Use safe work practices to protect yourself and limit the spread of contamination

- Keep hands away from face.
- Limit surfaces touched.
- Change gloves when torn or heavily contaminated.
- Perform hand hygiene.

Sequence for putting on personal protective equipment.

Reproduced from: Centers for Disease Control and Prevention. Protecting Healthcare Personnel: Sequence for Donning and Removing Personal Protective Equipment. Available at: https://www.cdc.gov/hai/prevent/ppe.html (Accessed on March 20, 2020).

Graphic 127473 Version 1.0

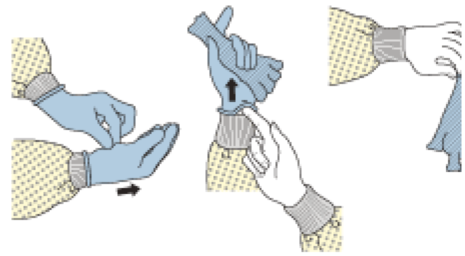
Taking off personal protective equipment

Example 1

There are a variety of ways to safely remove PPE without contaminating your clothing, skin, or mucous membranes with potentially infectious materials. Here is one example. **Remove all PPE before exiting the patient room** except a respirator, if worn. Remove th respirator **after** leaving the patient room and closing the door. Remove PPE in the following sequence:

1. Gloves

- Outside of gloves are contaminated!
- If your hands get contaminated during glove removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Using a gloved hand, grasp the palm area of the other gloved hand and peel off first glove.
- Hold removed glove in gloved hand.
- Slide fingers of ungloved hand under remaining glove at wrist and peel off second glove over first glove.
- Discard gloves in a waste container.

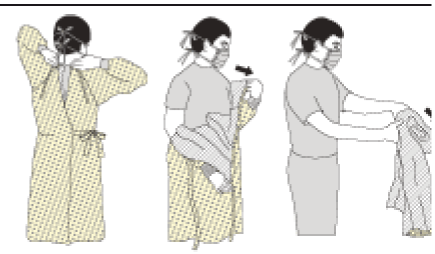


2. Goggles or face shield

- Outside of goggles or face shield are contaminated!
- If your hands get contaminated during goggle or face shield removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Remove goggles or face shield from the back by lifting head band or ear pieces.
- If the item is reusable, place in designated receptacle for reprocessing. Otherwise, discard in a waste container.

3. Gown

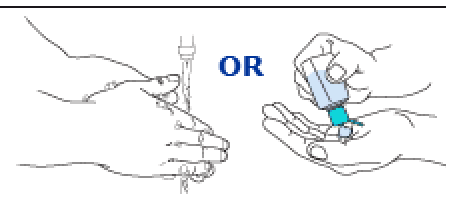
- Gown front and sleeves are contaminated!
- If your hands get contaminated during gown removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Unfasten gown ties, taking care that sleeves don't contact your body when reaching for ties.
- Pull gown away from neck and shoulders, touching inside of gown only.
- Turn gown inside out.
- Fold or roll into a bundle and discard in a waste container.



4. Mask or respirator

- Front of mask/respirator is contaminated. **DO NOT TOUCH!**
- If your hands get contaminated during mask/respirator removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Grasp bottom ties or elastics of the mask/respirator, then the ones at the top, and remove without touching the front.
- Discard in a waste container.

5. Wash hands or use an alcohol-based hand sanitizer immediately after removing all PPE



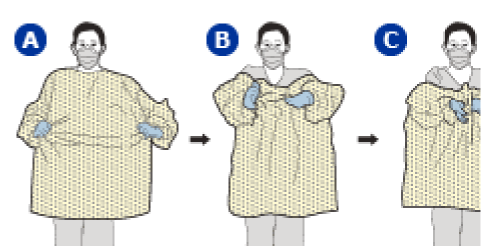
Perform hand hygiene between steps if hands become contaminated and immediately after removing all PPE

Example 2

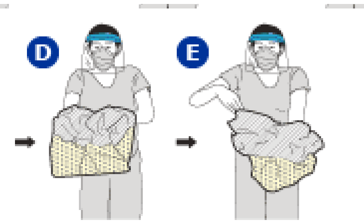
Here is another way to safely remove PPE without contaminating your clothing, skin, or mucous membranes with potentially infectious materials. **Remove all PPE before exiting the patient room** except a respirator, if worn. Remove the respirator **after** leaving the patient room and closing the door. Remove PPE in the following sequence:

1. Gown and gloves

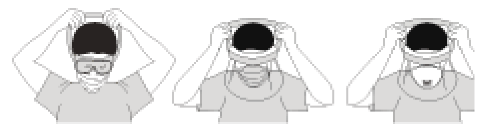
- Gown front and sleeves and the outside of gloves are contaminated!
- If your hands get contaminated during gown or glove removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Grasp the gown in the front and pull away from your body so that the ties break, touching outside of gown only with gloved hands.
- While removing the gown, fold or roll the gown inside-out into a bundle.
- As you are removing the gown, peel off your gloves at the same time, only



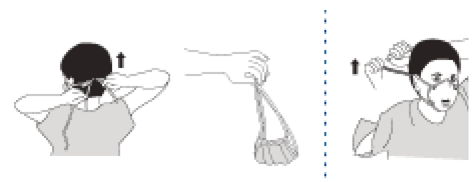
As you are removing the gown, peel off your gloves at the same time, only touching the inside of the gloves and gown with your bare hands. Place the gown and gloves into a waste container.



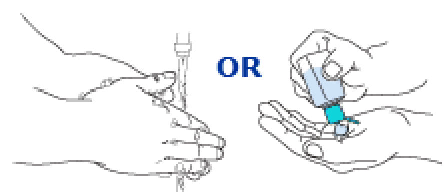
2. Goggles or face shield
- Outside of goggles or face shield are contaminated!
- If your hands get contaminated during goggle or face shield removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Remove goggles or face shield from the back by lifting head band and without touching the front of the goggles or face shield.
- If the item is reusable, place in designated receptacle for reprocessing. Otherwise, discard in a waste container.



3. Mask or respirator
- Front of mask/respirator is contaminated. **DO NOT TOUCH!**
- If your hands get contaminated during mask/respirator removal, immediately wash your hands or use an alcohol-based hand sanitizer.
- Grasp bottom ties or elastics of the mask/respirator, then the ones at the top, and remove without touching the front.
- Discard in a waste container.



4. Wash hands or use an alcohol-based hand sanitizer immediately after removing all PPE



Perform hand hygiene between steps if hands become contaminated and immediately after removing all PPE

Reproduced from: Centers for Disease Control and Prevention. Protecting Healthcare Personnel: Sequence for Donning and Removing Personal Protective Equipment. Available at: https://www.cdc.gov/hai/prevent/ppe.html (Accessed on March 20, 2020).

Graphic 127474 Version 1.0

Example of N95 mask

Reproduced from: N95 Respirators and Surgical Masks (Face Masks). U.S. Food & Drug Administration. Available at: https://www.fda.gov/medical-devices/personal-protective-equipment-infection-control/n95-respirators-and-surgical-masks-face-masks (Accessed on March 21, 2020).

Graphic 127476 Version 1.0

Endotracheal intubation while wearing powered air-purifying respirators

Two anesthesiologists using a videolaryngoscope for endotracheal intubation while wearing powered air-purifying respirators.

From: Hong-Fei Z, Lu-Long B, Lin Y, et al. Response of Chinese anesthesiologists to the COVID-19 outbreak. Anesthesiology 2020. DOI: 10.1097/ALN.0000000000003300.

Graphic 127475 Version 1.0

Venous air embolism during neurosurgery: Rapid overview

Risk factors

- Surgical site above the level of the heart; most common in the sitting position
- Surgery involving major intracranial venous structures

Clinical and monitoring signs/symptoms

- Immediate:
  - Air visible on TEE
  - Change in precordial Doppler tone
  - Cough, in awake patient
- May occur:*
  - Decrease in $ETCO_2$
  - Decreased blood pressure
  - Oxygen desaturation

Management

- Immediate:
  - Flood surgical field with saline; repair site of air entry
  - Administer IV fluid bolus
  - Administer 100% oxygen; discontinue nitrous oxide
- If blood pressure falls:
  - Call for help
  - Administer vasopressors
  - Aspirate air from CVC
- Lower head of the operating table if any of the following occur:
  - Air is visible in left heart on TEE
  - Significant hemodynamic compromise; need for or impending CPR
  - New neurologic deficit in awake patient

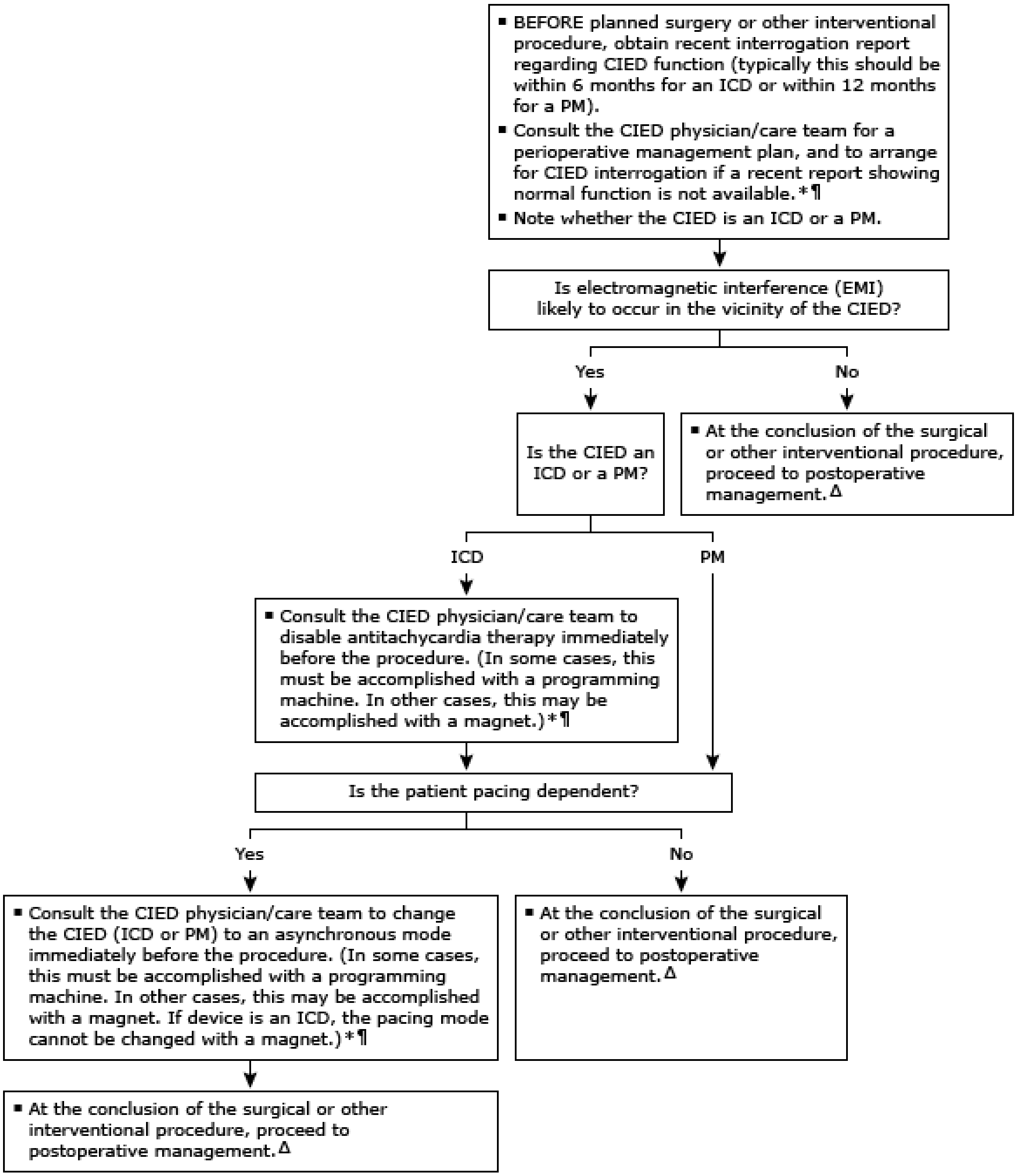
This table shows initial management of intraoperative VAE. Once VAE resolves, the decision to proceed with surgery should be multidisciplinary, considering the severity of the event, likelihood of recurrence, urgency of the surgery, and patient factors. For further information, refer to UpToDate content on intraoperative VAE.

TEE: transesophageal echocardiography; IV: intravenous; CVC: central venous catheter; VAE: venous air embolism; CPR: cardiopulmonary resuscitation.

* Manifestations depend on the severity of VAE. Decrease in $ETCO_2$ is nonspecific, and magnitude of change may not correlate with severity of VAE.

Graphic 132157 Version 1.0

Pre- and intraoperative management of patients with a pacemaker or implantable cardioverter-defibrillator*



CIED: cardiac implantable electronic device; ICD: implantable cardioverter-defibrillator; PM: pacemaker.

* Refer to UpToDate topics addressing perioperative management of patients with a pacemaker or implantable cardioverter-defibrillator.

¶ Factors considered by the CIED physician/care team in developing a perioperative management plan:

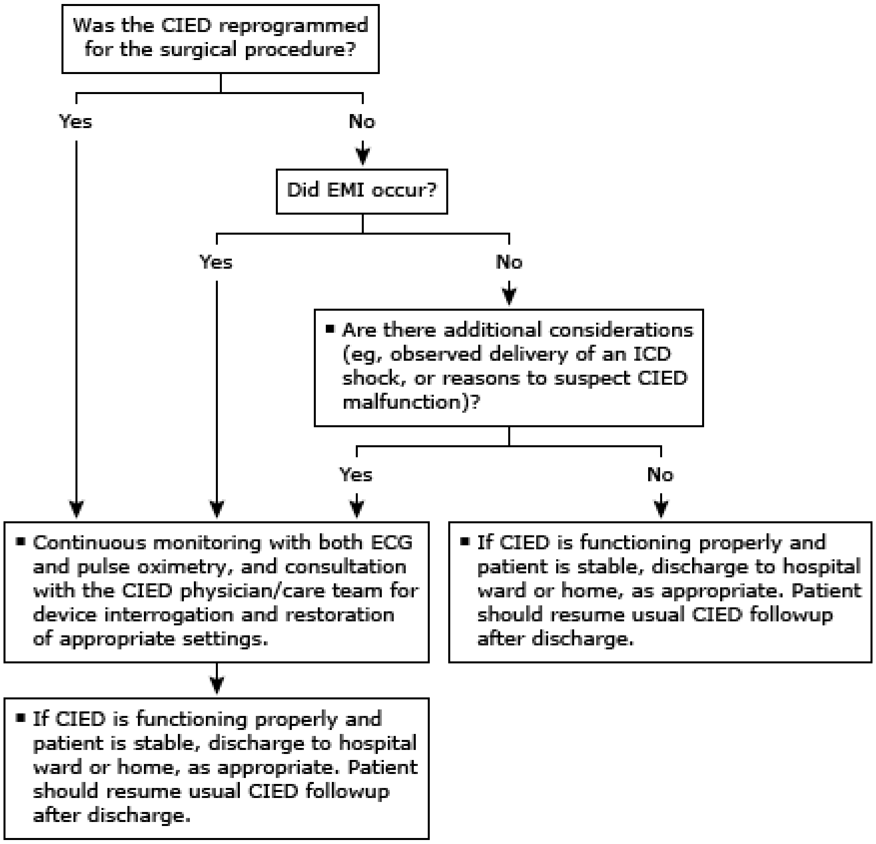
- Is the CIED programming optimal for the patient's current status?
- Should antitachycardia therapy be disabled?

- Is the patient pacing dependent and if so, is an asynchronous pacing mode needed?
- Is a more rapid pacing rate needed?
- Should rate response be disabled?
- Has the location of the surgical procedure and patient positioning been taken into consideration (eg, difficulties with maintaining a magnet in a stable position, inaccessibility of the magnet, or jeopardy to sterility of the surgical field)?
- Is the operative care team aware of the intraoperative and postoperative CIED management plan (eg, reprogramming or magnet use when indicated)?

Δ Refer to related UpToDate content.

Graphic 116023 Version 1.0

Postoperative management of patients with a pacemaker or implantable cardioverter-defibrillator*

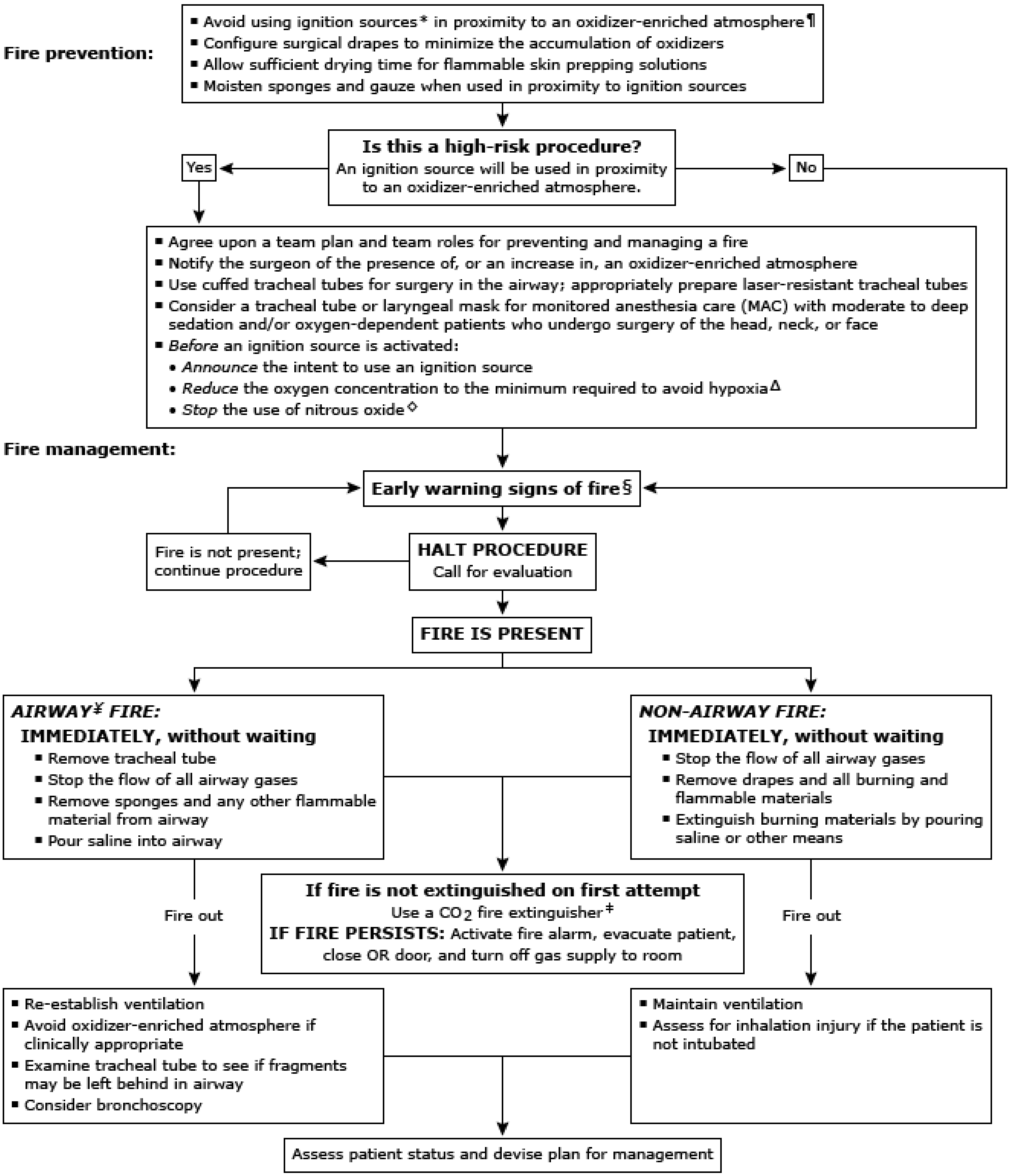


CIED: cardiac implantable electronic device; EMI: electromagnetic interference; PACU: post-anesthesia care unit; ICU: intensive care unit.

* Refer to UpToDate topics addressing perioperative management of patients with a pacemaker or implantable cardioverter-defibrillator.

Graphic 116028 Version 1.0

American Society of Anesthesiologists (ASA) operating room fires algorithm



Algorithm for prevention and management of an operating room (OR) fire.

---

* Ignition sources include but are not limited to electrosurgery or electrocautery units and lasers.

¶ An oxidizer-enriched atmosphere occurs when there is any increase in oxygen concentration above room air level, and/or the presence of any concentration of nitrous oxide.

Δ After minimizing delivered oxygen, wait a period of time (eg, one to three minutes) before using an ignition source. For oxygen-dependent patients, *reduce* supplemental oxygen delivery to the minimum required to avoid hypoxia. Monitor oxygenation with pulse oximetry, and, if feasible, inspired, inhaled, and/or delivered oxygen concentration.

◇ After stopping the delivery of nitrous oxide, wait a period of time (eg, one to three minutes) before using an ignition source.

§ Unexpected flash, flame, smoke or heat, unusual sounds (eg, a "pop," "snap," or "foomp") or odors, unexpected movement of drapes, discoloration of drapes or breathing circuit, unexpected patient movement or complaint.

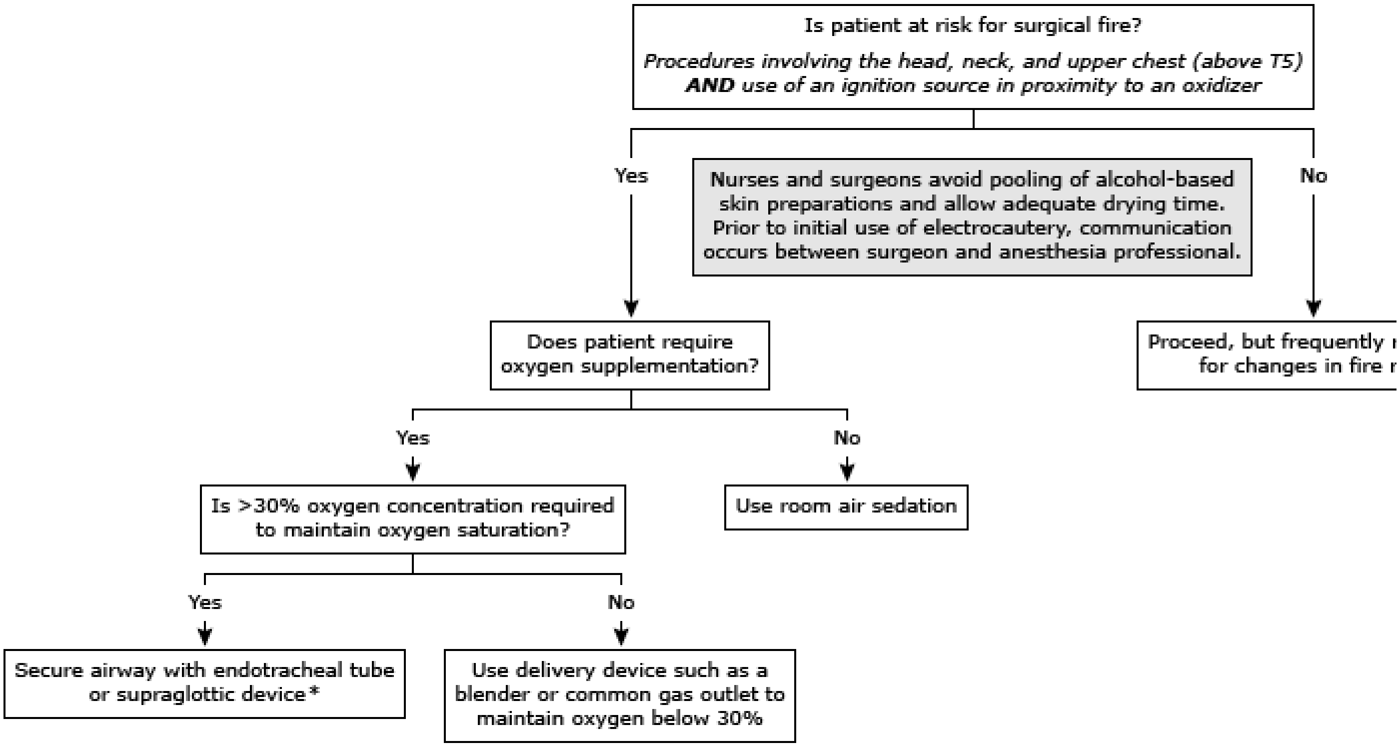
¥ In this algorithm, airway fire refers to a fire in the airway or breathing circuit.

‡ A CO_2 fire extinguisher may be used on the patient if necessary.

From: Apfelbaum JL, Caplan RA, Barker SJ, et al. Practice advisory for the prevention and management of operating room fires: an updated report by the American Society of Anesthesiologists Task Force on Operating Room Fires. Anesthesiology 2013; 118:271. DOI: 10.1097/ALN.0b013e31827773d2.

Graphic 103356 Version 4.0

Anesthesia Patient Safety Foundation (APSF) fire prevention algorithm



The Anesthesia Patient Safety Foundation presents a simplified approach to management of surgical fire ris

---

* Although securing the airway is preferred, for cases where using an airway device is undesirable or not fea oxygen accumulation may be minimized by air insufflation over the face and open draping to provide wide exposure of the surgical site to the atmosphere.

Reproduced with permission from: Stoelting RK, Feldman JM, Cowles CE, Bruley ME. Surgical fire injuries continue to occur: Prevention require more cautious use of oxygen. APSF Newsletter 2012; 26:41. Copyright © 2012 Anesthesia Patient Safety Foundation. Updated information from the 2014 APSF OR Fire Prevention Algorithm.

Graphic 103357 Version 2.0

Contributor Disclosures

Joyce A Wahr, MD, FAHA Other Financial Interest: Anesthesia Patient Safety Foundation [Anesthesia patient safety]. All of the relevant financial relationships listed have been mitigated. **Roberta Hines, MD** No relevant financial relationship(s) with ineligible companies to disclose. **Nancy A Nussmeier, MD, FAHA** No relevant financial relationship(s) with ineligible companies to disclose.

Contributor disclosures are reviewed for conflicts of interest by the editorial group. When found, these are addressed by vetting through a multi-level review process, and through requirements for references to be provided to support the content. Appropriately referenced content is required of all authors and must conform to UpToDate standards of evidence.

Conflict of interest policy

→