Prevention of Healthcare-associated Infections in Intensive Care Unit Patients

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Healthcare-associated infections are common in hospitalized patients, impacting 7 to 10% of patients globally.[1] In lower- and middle-income countries, the risk is 15%, with surgical site infection being most common.[2] In higher-income countries, healthcare-associated infections affect up to 30% of intensive care unit (ICU) patients who are vulnerable because of underlying comorbidities and immunosuppression and the presence of invasive catheters and devices.[1] In this review, we summarize current evidence-based strategies for healthcare-associated infection prevention in ICU patients. Healthcare-associated infection risk factors, treatment, and severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) prevention are not discussed in this review.

Epidemiology

The 2019 Centers for Disease Control and Prevention Healthcare-associated infection progress report, which includes data from many but not all acute care hospitals in the United States, reported 29,669 central line–associated bloodstream infections, 26,376 catheter-associated urinary tract infections, and 4,423 ventilator-associated events in patients from more than 3,600 hospitals.[3] These statistics underestimate the total healthcare-associated infection burden in the United States because not all healthcare-associated infections are required to be reported.

Mortality, Costs, and Reporting

Healthcare-associated infections impact morbidity, mortality, and healthcare cost. According to the World Health Organization (Geneva, Switzerland), healthcare-associated infections cause 37,000 deaths per year in Europe and 99,000 deaths per year in the United States.[1] Healthcare-associated infections with multidrug-resistant organisms increase in-hospital mortality 2-fold.[4] Enterobacterales species (*e.g.*, *Klebsiella pneumoniae*, *Escherichia coli*) are the most common causative organisms in multidrug-resistant infections.[5] Surgical site infection, central line–associated bloodstream infection, and ventilator-associated events are strongly associated with mortality, whereas catheter-associated urinary tract infection is not consistently associated with mortality.[5–7]

Healthcare-associated infections increase healthcare costs in Europe by €7 billion per year and in the United States by $6.5 billion per year.[1] Surgical site infections, particularly deep surgical site infections, are associated with up to a $20,000 increase in cost per patient admission.[8] Increased healthcare costs from healthcare-associated infections are borne by the government, insurance companies, patients, and hospitals. In the United States, central line–associated bloodstream infection, catheter-associated urinary tract infection, *Clostridioides difficile* infection, and some surgical site infections are reported by acute care hospitals to the Centers for Disease Control and Prevention (Atlanta, Georgia) *via* the National Healthcare Safety Network. Hospitals with high healthcare-associated infection rates have reduced global reimbursement or additional financial penalties under the Centers for Medicare and Medicaid Services (Baltimore, Maryland) pay for performance value-based purchasing program. Conversely, hospitals with low healthcare-associated infection rates may receive financial rewards. Individual hospital healthcare-associated infection rates are publicly reported in a format that allows for comparison between hospitals.

Appropriate Perioperative Antibiotic Prophylaxis

Appropriate perioperative antibiotic prophylaxis is an important component of surgical site infection prevention. The Surgical Care Improvement Program, run by the Centers for Medicare and Medicaid Services and Centers for Disease Control and Prevention between 2005 and 2015, included three measures related to perioperative antibiotic prophylaxis, timing, drug appropriateness, and drug discontinuation after surgery. In an observational study of almost 80,000 patients, continuation of prophylactic antibiotics for more than 24 h after surgery was independently associated with increased risk of acute kidney injury and *C. difficile* infection.[9] A meta-analysis, which included 52 randomized controlled trials, found no benefit of continuing antibiotics for more than 24 h postoperatively.[10] In ICU patients with open abdominal or sternal wounds, there is no evidence to support extended antibiotic prophylaxis, despite the fact that bacterial colonization increases in the

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wound over time.[11–13] Taken together, these data suggest that routine antibiotic prophylaxis should not be continued for more than 24 h, unless a specific infection is suspected.

Hand Hygiene and Transmission-based Precautions

The Centers for Disease Control and Prevention core infection prevention and control practices for safe healthcare delivery in all settings recommendations provide guidance for healthcare workers on practices to prevent healthcare-associated infections (www.cdc.gov/hipac/pdf/core-practices.pdf [accessed August 1, 2021]; table 1).[14] These practices include hand hygiene, environmental disinfection, injection and medication safety, use of personal protective equipment, minimization of potential exposures, appropriate reprocessing of reusable medical equipment, transmission-based precautions, removal of temporary medical devices when feasible, and occupational measures that include vaccination and sick leave for healthcare workers.

The Centers for Disease Control and Prevention categorizes microbial transmission into three categories: contact transmission (direct and indirect), droplet transmission, and airborne transmission.[15] Contact transmission is the most common route by which healthcare-associated infections are spread in the ICU. Practices that limit contact transmission of infectious agents include hand hygiene, use of single-patient rooms, correct use of personal protective equipment (proper donning/doffing of gowns and gloves), use of disposable medical equipment, and proper disinfection of rooms between patient use.

Hands are the most common fomite for spreading healthcare-associated infections in ICU patients, and multiple medical devices can serve as fomites, including soap/sanitizer dispensers, humidifiers, nebulizers, pressure transducers, stethoscopes, suction catheters, thermometers, and ultrasound probes.[16] For hand hygiene, the Centers for Disease Control and Prevention recommends alcohol-based hand sanitizer, unless one's hands are visibly soiled or the patient is infected with *C. difficile*. In these cases, the Centers for Disease Control and Prevention recommends hand washing with soap and water. Alcohol-based hand sanitizers increase hand hygiene compliance because of convenience and time efficiency compared with traditional hand washing.[17] Hand hygiene should be performed (1) before touching a patient, (2) before performing an aseptic task, (3) before moving from a soiled body part to a clean body part, (4) after touching the patient or their immediate environment, and (5) immediately after glove removal.[14]

When soap and water are used, it is recommended that the provider's hands are wet, soap is applied, hands are rubbed together for at least 15 s, hands are rinsed with clean water, and the faucet is turned off with a disposable towel. The Centers for Disease Control and Prevention does not recommend use of anti-bacterial soap. For alcohol-based hand sanitizers, the appropriate dose depends on the manufacturer's instructions. The World Health Organization recommends applying a "coin sized" amount of hand sanitizer during each application. Appropriate hand hygiene is associated with a reduction in healthcare-associated infection incidence of up to 50%, including a 50% reduction in methicillin-resistant *Staphylococcus aureus* infection.[18]

For respiratory pathogens, droplet transmission occurs when infectious agents are carried in small water droplets (typically larger than 5 μm) that are exhaled from the respiratory tract. The maximum distance that infectious droplets can travel is not known and depends on particle size, velocity, and environmental temperature and humidity. The Centers for Disease Control and Prevention acknowledges that some infectious respiratory droplets travel up to 6 feet from their source.[15] Examples of pathogens that are spread by droplet transmission include influenza, adenoviruses, and *Mycoplasma pneumoniae*. Airborne transmission occurs by spread of droplet nuclei (desiccated droplets) which are less than 5 μm or other small infectious particles. *Mycobacterium tuberculosis* and *Varicella zoster* are classic pathogens spread by airborne transmission. The dichotomy between droplet and airborne transmission based on particle size is a somewhat artificial construct, with the amount of pathogen spread affected by multiple factors (*e.g.*, humidity, air temperature, total number of infectious particles, and ventilation conditions), and hence droplet or airborne transmission should be considered as general guidance on how a pathogen is spread. The recent coronavirus disease 2019 pandemic has highlighted the need for further research into the numerous factors that affect respiratory pathogen spread.

Staffing

Hospital infection prevention departments with dedicated personnel to perform healthcare-associated infection surveillance and implement control measures are an important aspect of healthcare-associated infection reduction. In the 1980s, these measures were found to be cost-effective and substantially reduced healthcare-associated infections.[19] Ensuring adequate nurse staffing is similarly critical, because nurse shortages with increased patient to nurse ratios are associated with increased healthcare-associated infection incidence.[20,21]

Catheter-associated Urinary Tract Infection

Catheter-associated urinary tract infection is the most common healthcare-associated infection in hospitalized patients. More than 30 million urinary catheters are placed in the United States annually, and the risk for bacteriuria increases by 3 to 7% for every day with an indwelling catheter.[22] Although the unadjusted mortality for catheter-associated urinary tract infection is high in retrospective cohort studies, catheter-associated urinary tract infection is not consistently associated with mortality after risk adjustment, and bacteremia is rare.[6,23] Nevertheless, catheter-associated

Table 1. Centers for Disease Control and Prevention Recommended Strategies for Preventing Device-related and Surgical Site Infections

Healthcare-associated Infection	Recommended Prevention Strategies
Central line–associated bloodstream infection	Site selection 1. Avoid using the femoral vein when possible (Category IA) 2. Use the subclavian vein rather than the femoral vein or internal jugular vein when possible (Category IB) 3. Use a catheter with the minimum number of necessary ports (Category IB) Placement 1. Wear sterile gloves during catheter placement (Category IA) 2. Perform hand hygiene with soap and water or alcohol-based sanitizer before catheter placement (Category IB) 3. Use maximal sterile precautions (Category IB) 4. Clean the patient's skin with > 0.5% chlorhexidine with alcohol, iodine, or 70% alcohol in patients with a chlorhexidine allergy before catheter placement (Category IB) 5. Allow antiseptics to dry according to the manufacturer's instructions (Category IB) Dressing and securing 1. Use a sterile, semipermeable, transparent dressing to cover the catheter insertion site (Category IA) 2. Replace the dressing if damp, loose, or soiled (Category IB) 3. Replace transparent dressings every 7 days (Category IB) 4. Use a sutureless securing device (Category II) Replacement 1. Do not routinely replace catheters (Category IB) 2. Do not perform guidewire exchanges to prevent infection (Category IB) 3. Remove a catheter within 48 h if it was placed without aseptic technique (Category IB) 4. Do not remove catheters based on fever alone (Category II) Removal 1. Promptly remove a catheter that is no longer needed (Category IA)
Catheter-associated urinary tract infection	Appropriate use 1. Minimize catheter days, particularly in high-risk patients such as the elderly, women, and those who are immunosuppressed (Category IB) 2. Remove catheters as soon as possible after surgery, ideally within 24 h (Category IB) 3. Use external urinary collection devices in cooperative patients who do not have urinary retention or obstruction (Category II) 4. Use intermittent catheterization rather than an indwelling catheter in patients with bladder emptying dysfunction (Category II) Insertion technique 1. Perform appropriate hand hygiene before insertion or manipulation of a catheter (Category IB) 2. Insert catheters using aseptic technique and sterile equipment (Category IB) 3. Use sterile gloves, drape, and aseptic solution to clean the periurethral space before catheter insertion (Category IB) 4. Secure indwelling catheters to prevent movement and urethral traction (Category IB) 5. Perform intermittent catheterization at regular intervals in patients with urinary retention (Category IB) 6. Use ultrasound to assess bladder volume and help guide the timing of intermittent catheterization (Category II) 7. Use the smallest catheter possible to prevent urethral and bladder trauma (Category II) Maintenance 1. Maintain a closed drainage and collection system (Category IB) 2. Replace the catheter and collection system if there are any breaks that compromise sterility (Category IB) 3. Maintain unobstructed urine flow by avoiding kinks and maintaining the drainage bag below the bladder (Category IB) 4. Do not give prophylactic antibiotics to prevent catheter-associated urinary tract infection (Category IB) 5. Do not routinely clean the periurethral area with antiseptics (Category IB) 6. If urine is needed for culture, sample it from a needleless port with a sterile syringe after cleaning the area (Category IB) 7. Do not irrigate the bladder, catheter, and collection system with antibiotics (Category II) 8. Do not change urinary catheters or collection bags at regular, fixed intervals (Category II) Quality improvement 1. Implement quality improvement programs to reduce inappropriate catheter use and ensure proper hand hygiene (Category IB) Infrastructure 1. Provide guidelines on catheter insertion, maintenance, and removal (Category IB) 2. Provide periodic in-service training to medical personnel (Category IB) 3. Dedicate personnel and resources to surveillance of catheter-associated urinary tract infections (Category IB) 4. Perform documentation of the indication for catheterization, date of insertion, person who inserted the catheter, and date of removal (Category II) Surveillance 1. Use standardized methods for surveillance such as the number of infections per 1,000 catheter days or catheter utilization ratio (Category IB) 2. Do not perform routine surveillance for asymptomatic bacteriuria (Category II)

(*Continued*)

Table 1. (Continued)

Healthcare-associated Infection	Recommended Prevention Strategies
Surgical site infection	Antibiotics 1. Do not administer additional antibiotics in clean and clean-contaminated cases after the surgical incision is closed in the operating room (Category IA) 2. Administer intravenous antibiotics so that a therapeutic drug concentration is obtained at the time of skin incision (Category IB)* 3. Do not apply topical antibiotics such as ointments, powders, or solutions to the surgical incision to prevent infection (Category IB) Glycemic control 1. Target a blood glucose concentration less than 200 mg/dl during the perioperative period (Category 1A) Temperature management 1. Maintain normothermia (36 to 38°C) during the perioperative period (Category IA) Oxygenation 1. In patients receiving general anesthesia with endotracheal intubation, administer a high FIO_2 during surgery and in the immediate postoperative period (Category IA)† Antiseptic practices 1. Bathe patients with soap or antiseptic the night before surgery (Category IB) 2. Prepare patients with an alcohol-based antiseptic before skin incision in the operating room (Category IA) Blood transfusion 1. Do not withhold blood transfusion to prevent surgical site infection if indicated (Category IB)

Further information on healthcare-associated infection prevention can be found at https://www.cdc.gov/infectioncontrol/guidelines/index.html. The most recent Centers for Disease Control and Prevention (Atlanta, Georgia) guidelines are from 2011 for central line–associated bloodstream infection, 2009 for catheter-associated urinary tract infection, and 2017 for surgical site infection. The categories of recommendations used by the Centers for Disease Control and Prevention are as follows: Category IA, strong recommendation supported by high- to moderate-quality evidence; Category IB, strong recommendation supported by low-quality evidence; and Category II, weak recommendation supported by any quality of evidence.

*No specific timing of administration is currently recommended by the Centers for Disease Control and Prevention, but published studies suggest that intravenous antibiotics should be administered within 120 min and ideally within 60 min of skin incision so that therapeutic levels can be reached in tissues. †More recent studies (after 2017) have suggested that a high inspired oxygen concentration may not be effective in reducing surgical site infection, and the World Health Organization (Geneva, Switzerland) guideline development committee for surgical site infection prevention changed their recommendation from strong to conditional for using a high inspired oxygen concentration during the perioperative period to prevent surgical site infection.

FIO_2, fractional inspired oxygen tension; ICU, intensive care unit.

urinary tract infection is a well established risk factor for increased ICU and hospital length of stay. In 2008, the Centers for Medicare and Medicaid Services designated catheter-associated urinary tract infection as a hospital-acquired complication, which would not be reimbursed.[24]

In the United States, catheter-associated urinary tract infection is diagnosed if a patient fulfills symptomatic urinary tract infection criteria and has an appropriate duration of catheterization.[25] Catheter-associated urinary tract infection is defined by three criteria: (1) the presence of a urinary catheter for more than 2 consecutive days in an inpatient location on the day of the event (includes catheters present for any portion of the calendar day on the day of the event or if removed the day before the event); (2) at least one of the following: suprapubic tenderness, costovertebral angle pain, urinary urgency, urinary frequency, or dysuria; and (3) a urine culture with no more than two species of pathogenic organisms, at least one of which is quantified as at least $\geq 10^5$ colony-forming units/ml.[25] Catheter-associated urinary tract infection does not occur secondary to other sites of infection, and *Candida*, parasites, mold, and dimorphic fungi are excluded.[25]

In ICU patients, urinary catheters are not universally required, and policies that promote early removal reduce catheter-associated urinary tract infection.[26–28] Catheters may be indicated in ICU patients when strict input/output recording is required during the first 48 h of shock, during active titration of vasopressors or inotropes, during diuresis for acute cardiac or pulmonary failure (when hourly monitoring is required to assess therapy), for active monitoring of acute or impending renal failure, or for frequent assessment of intravascular volume in patients with neurologic conditions that disrupt normal fluid balance (*e.g.*, diabetes insipidus).[22,27,28]

The U.S. Agency for Healthcare Research and Quality (Rockville, Maryland) lists numerous tools for implementing policies, procedures, and practices for reducing catheter-associated urinary tract infection with a comprehensive unit-based safety program (https://www.ahrq.gov/hai/tools/cauti-hospitals/toolkit-impl.html [accessed August 1, 2021]). The effect of the comprehensive unit-based safety program on a national level was assessed by Saint *et al.*,[29] showing a reduction in catheter-associated urinary tract infection in non-ICUs, but no change in ICUs. Although the quality of evidence for most individual interventions is low, sustained reductions in catheter-associated urinary tract infection have been achieved when multiple evidence-based interventions are "bundled."[30]

Ventilator-associated Events and Ventilator-associated Pneumonia

Ventilator-associated pneumonia is the most common healthcare-associated infection in the ICU, occurring

in approximately 10% of patients on mechanical ventilation.[31] Two systematic reviews by Melsen *et al.*[32,33] reported a pooled relative mortality risk of 1.27 (95% CI, 1.15 to 1.39) and a 13% attributable mortality with ventilator-associated pneumonia. Some studies have questioned ventilator-associated pneumonia's attributable mortality because of confounding, heterogeneity, and inappropriate accounting of the time-dependent nature of events leading to ventilator-associated pneumonia.[34]

In 2013, the Centers for Disease Control and Prevention proposed an algorithmic approach for ventilator-associated event *surveillance*.[35] The three definition tiers are (1) ventilator-associated condition; (2) infection-related ventilator-associated complication; and (3) possible ventilator-associated pneumonia. To be eligible for a ventilator-associated event, a patient must be mechanically ventilated for at least 4 days with the day of intubation counted as day 1. A ventilator-associated condition is defined by worsening oxygenation for at least 2 calendar days (increased positive end expiratory pressure or F_{IO_2}), whereas infection-related ventilator-associated complication is defined by worsening oxygenation with other features suggestive of infection (*e.g.*, fever or hypothermia, leukocytosis, or initiation of antibiotics for at least 4 days). Possible ventilator-associated pneumonia occurs when one or more of the following criteria are met after a patient develops indicators of worsening oxygenation 3 calendar days after beginning mechanical ventilation: (1) a positive culture from an endotracheal aspirate (more than 10^5 colony-forming units/ml), bronchoalveolar lavage (at least 10^4 colony-forming units/ml), lung tissue (at least 10^4 colony-forming units/ml), or protected specimen brush (at least 10^3 colony-forming units/ml); (2) purulent secretions, defined as lung, bronchial, or tracheal that contain at least 25 neutrophils and at most 10 squamous epithelial cells per low power field *plus* an organism identified by a respiratory specimen obtained as described in criterion 1; and/or (3) a positive diagnostic test identifying an organism in pleural fluid, lung histopathology, *Legionella* species, or a respiratory virus.

Ventilator-associated pneumonia can be clinically diagnosed in any patient who is mechanically ventilated for 48 h or more and develops a new or progressive infiltrate on chest radiography with associated signs and symptoms of infection (*e.g.*, purulent sputum, new fever or hypothermia, leukocytosis, worsening oxygenation, altered respiratory mechanics) and a positive respiratory specimen.[34,36] Different strategies have been proposed for obtaining diagnostic samples for ventilator-associated pneumonia. In a large multicenter randomized trial, endotracheal aspirates with nonquantitative cultures were not associated with different clinical outcomes or antibiotic use when compared to patients who had quantitative cultures performed by bronchoalveolar lavage.[37] In a subsequent systematic review that included 5,064 patients, including 1,367 patients from five randomized controlled trials, similar clinical outcomes were observed when invasive *versus* noninvasive diagnostic strategies were compared.[38] Additional research in this area is required, as there is no "gold standard" for the diagnosis of ventilator-associated pneumonia. Recent work with multiplex polymerase chain reaction–based assays has demonstrated shorter time to identification of pathogens and resistance patterns, as well as an association with faster discontinuation of antibiotics and earlier identification of patients with secondary infections.[39–41]

The strongest evidence for ventilator-associated pneumonia prevention relates to minimizing sedation and mechanical ventilation, improving physical conditioning, minimizing pooled secretions above the endotracheal tube cuff, and elevating the head of the bed 30 to 45 degrees. Recent evidence has brought into question other previously recommended interventions. For example, closed endotracheal suctioning does not consistently reduce ventilator-associated pneumonia.[42] Oral care with chlorhexidine is most effective in cardiac surgical patients but is of questionable efficacy in other ICU patients.[43] Selective digestive decontamination is not effective in ICUs with high rates of antibiotic resistance and is not recommended by the Infectious Disease Society of America or the Centers for Disease Control and Prevention.[42,44] The risks of selective digestive decontamination are also not fully understood. Subglottic suction drainage may prevent ventilator-associated pneumonia but does not shorten mechanical ventilation time or ICU length of stay.[34] Stress ulcer prophylaxis may increase ventilator-associated pneumonia but often cannot be avoided because of strong indications.[42]

Interventions that are *not* currently recommended for ventilator-associated pneumonia prevention include regular monitoring of gastric residual volumes, closed endotracheal suctioning, early parenteral nutrition, routine prone positioning, and kinetic beds.[34,42] Early *versus* late tracheostomy is controversial. Previous systematic reviews concluded that early tracheostomy did not reduce ventilator-associated pneumonia[45]; however, a more contemporary systematic review and meta-analysis that included 3,145 patients found that early tracheostomy (at less than 7 days after initiation of mechanical ventilation) was associated with reduced ventilator-associated pneumonia (odds ratio, 0.59 [95% CI, 0.35 to 0.99]) and more ventilator-free days.[46] In their most recent guidelines, the Infectious Disease Society of America (Arlington, Virginia) does not endorse early tracheostomy to reduce ventilator-associated pneumonia.[36]

Central Line–associated Bloodstream Infection

Central line–associated bloodstream infection is associated with significant morbidity and mortality. ICU patients with multiple central lines are particularly vulnerable. The findings from the 2003 Michigan Keystone ICU study were pivotal, resulting in widespread practice change. Implementation of

a simple evidence-based bundle (hand hygiene, full-barrier precautions during insertion, chlorhexidine to clean the insertion site, avoiding the femoral veins when possible, and removing unnecessary central lines) at over 100 ICUs resulted in a significant, sustained infection reduction; 7.7 central line–associated bloodstream infections per 1,000 catheter days at baseline to 1.4 at 16 to 18 months post intervention.[47] This study highlighted that large-scale healthcare-associated infection reduction requires practice and behavior change and synergy of technical (*e.g.*, central line insertion checklists, ensuring chlorhexidine availability) and adaptive (*e.g.*, forming a safety culture, engaging front line leaders, gaining hospital executive support) prevention strategies.

Chlorhexidine is used as an adjunct for central line–associated bloodstream infection prevention beyond central line insertion. Chlorhexidine-impregnated dressings have been shown to reduce central line–associated bloodstream infection rates (from 1.3 to 0.4 per 1,000 catheter days) when studied in a seven-ICU randomized controlled trial.[48] A systematic review and meta-analysis that included 17 trials found that daily chlorhexidine bathing was associated with a 56% relative risk reduction for central line–associated bloodstream infection. Chlorhexidine bathing was also associated with decreased methicillin-resistant *S. aureus* colonization.[49]

C. difficile Infection

C. difficile infection occurs in the setting of a disrupted normal gut microbiome when *C. difficile* proliferates beyond host immune control and produces toxins A and B, which disrupt the normal cytoskeletal structure of colonic epithelial cells causing diarrhea, paralytic ileus, and in rare cases colonic perforation. Broad-spectrum antibiotics are a common instigator for *C. difficile* infection because they alter the normal gut microbiome allowing *C. difficile,* if present in the colon, to proliferate.

The main prevention strategies for *C. difficile* infection are eliminating transmission of the organism from patient to patient or from an infected patient to the ICU environment. *C. difficile* can exist in a hardy spore form, which has the ability to persist on surfaces, spreading to patients' and healthcare workers' hands. *C. difficile* typically requires a bleach-based product for disinfection, but select non-bleach–based products are also sufficient. A list of appropriate disinfectants can be found on the U.S. Environmental Protection Agency (Washington, D.C.) website (https://www.epa.gov/sites/default/files/2021-02/documents/02-22-2021_list-k.pdf [accessed August 1, 2021]). "No-touch" technologies such as ultraviolet light may be a useful adjunct in limiting *C. difficile* infection. One randomized controlled trial in nine hospitals demonstrated a significant reduction in *C. difficile* infection when disinfecting ultraviolet light was added to standard terminal room cleaning procedures.[50] Further studies are needed to confirm the efficacy of disinfecting ultraviolet light.

Patients with *C. difficile* colonization or infection should be placed in a private room, and healthcare workers should don gowns and gloves upon room entry. Hand hygiene with soap and water, as opposed to alcohol-based hand sanitizer, is important after glove removal, to ensure adequate spore removal. Gastric acid suppression facilitates *C. difficile* reaching the colon, because normal stomach pH is altered. Hence, judicious use of proton pump inhibitors and other gastric acid suppressants is an important aspect of *C. difficile* infection prevention.[51]

Finally, *C. difficile* proliferation and toxin production can be prevented by maintaining a normal gut microbiome. Antibiotics and chemotherapy are the most common disrupters of the normal colonic microbiome. Antimicrobial stewardship is key in *C. difficile* infection prevention. Approximately 30% of antibiotics prescribed in U.S. acute care hospitals are unnecessary or suboptimal.[52] Ensuring that antibiotics are given only when necessary, are as narrow-spectrum as possible, and are given for the shortest effective duration is the cornerstone of *C. difficile* infection prevention. Fecal transplant, to restore the normal gastrointestinal microbiome, is a successful strategy to prevent recurrent *C. difficile* infection.[53]

Appropriate Diagnostic Testing

Inappropriate diagnostic testing for healthcare-associated infections increases healthcare cost, and testing should be performed only when clinically indicated. Figure 1 shows one potential algorithm for appropriate diagnostic testing in ICU patients with suspected infection. Targeted cultures should be obtained in (1) patients who have fever or are hypothermic *and* who have a significant change in their clinical condition or (2) patients who have fever or are hypothermic, have no significant change in their clinical condition, and have not had surgery within 24 h but have a high suspicion for a specific infection based on other clinical or laboratory findings.

Conclusions

Healthcare-associated infections continue to burden ICU patients with excess morbidity, mortality, and cost. Given these issues and the fact that healthcare-associated infections lead to financial penalties for hospitals, it is critical for ICU providers to understand evidence-based prevention strategies. Healthcare-associated infection prevention also offers an opportunity for anesthesiologists to lead important research, quality improvement, and policy development efforts within acute care hospitals. More widespread adoption of best practices will lead to improvements in patient outcomes and cost reductions in U.S. healthcare.

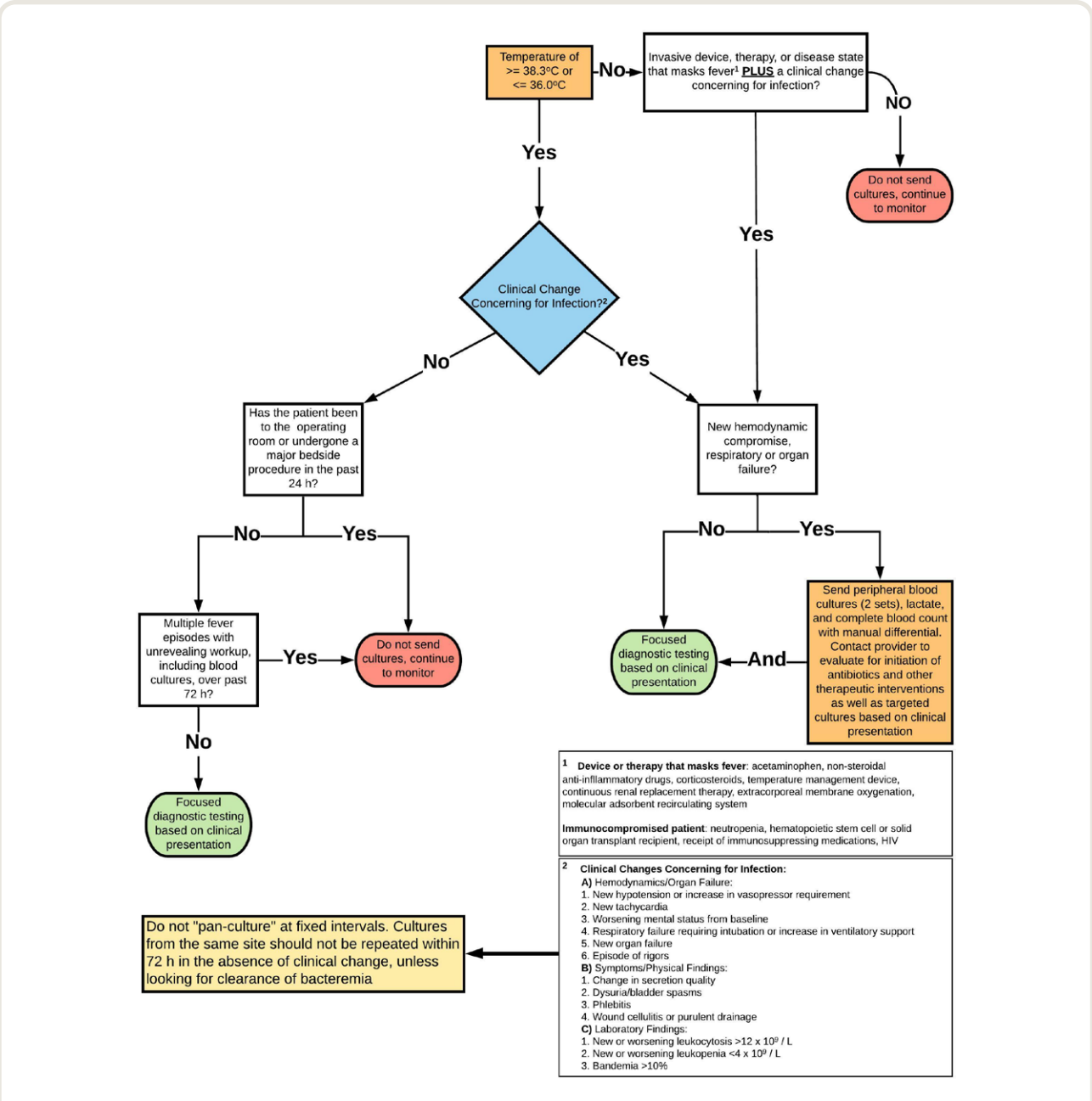

Fig. 1. A potential algorithm for obtaining appropriate cultures in an intensive care unit patient with a suspected healthcare-associated infection. Focused diagnostic testing is based on clinical presentation. HIV, human immunodeficiency virus.

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Competing Interests

Dr. Mazzeffi has active research grant funding from the Society of Cardiovascular Anesthesiologists (Chicago, Illinois) and has previously received compensation for consulting from HemoSonics Corporation (Charlottesville, Virginia). Dr. Galvagno has active research grant funding from the U.S. Department of Defense (Wright-Patterson Air Force Base, Ohio, and Fort Detrick, Frederick, Maryland). He has also previously received honoraria from Up to Date (Waltham, Massachusetts), the American Board of Anesthesiology (Raleigh, North Carolina), and the American Board of

Psychiatry and Neurology (Deerfield, Illinois). He reports receiving speaking fees for Northwest Anesthesia Seminars (Pasco, Washington) and compensation for medical-legal expert reviews. Dr. Rock has active research grant funding from the Centers for Disease Control and Prevention (Atlanta, Georgia; Epicenter grant). She is also the founder and owner of Infection Prevention Strategy Consulting LLC (Baltimore, Maryland).

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