Health-care–associated infections (HAIs) remain a leading cause of perioperative morbidity and mortality, contributing substantially to rising health-care costs. Currently, one out of every 10 surgical patients develops an HAI [1]. Several factors predispose surgical patients to the development of infection. One is the insult of surgery, which causes corticosteroid and catecholamine release resulting in transient immunodeficiency [2]. Another is postsurgical pain, which leads to immobility and facilitates the development of atelectasis and subsequently pneumonia. Additionally, surgical patients often require the placement of indwelling devices, promoting infection through barrier compromise and biofilm formation. The authors will briefly review three of the most commonly acquired HAIs, focusing predominantly on preventive strategies specific to each infection.

Health-care–associated pneumonia

A. Epidemiology

Health-care–associated pneumonia (HAP) is defined as any case of pneumonia beginning 48 hours or more following admission. In the case of ventilated patients, this is referred to as ventilator-associated pneumonia (VAP). Although HAP is the second most frequent HAI, it accounts for most HAIs in intensive care unit (ICU) patients and is the most lethal [3,4]. Aspiration of oropharyngeal and gastric contents is the leading cause of HAP. The time of acquisition determines the causative organism. Early-onset pneumonia (≤96 hours following admission) is caused by Escherichia coli, Klebsiella spp, Streptococcus pneumoniae, Haemophilus influenzae, and...
Staphylococcus aureus, while late-onset pneumonia is associated with methicillin-resistant S. aureus (MRSA) and Pseudomonas aeruginosa [5]. Box 1 lists the most common risk factors associated with HAP.

B. Diagnosis and treatment

Traditionally, diagnosis of HAP relied on the presence of fever, cough, or purulent sputum, with a new or progressive infiltrate on a chest radiograph [6]. Over the past decade, efforts have been made to improve diagnostic utility through the use of quantitative culture and lower airway sampling via bronchoalveolar lavage or protected brush specimen. Currently, high-level evidence is insufficient to suggest definitively that either improves outcome [7,8]. But the invasive approach to VAP diagnosis provides a more accurate microbiologic diagnosis. Whether these techniques will prove superior in multicenter prospective trials is yet to be determined. Treatment of HAP requires early initiation of empiric broad-spectrum antibiotics narrowed once microbiological profiles become available. Past recommendations for treatment duration have been 14 to 21 days [5]. However, a recent randomized trial by Chastre et al. [9] suggests 8 days is equivalent to 15 days for the treatment of VAP.

**Box 1. Risk factors associated with health-care–associated pneumonia**

- Administration of antacids or histamine type-2 antagonists
- Supine positioning
- Coma
- Paralytics
- Enteral nutrition
- Nasogastric tube
- Reintubation
- Tracheostomy
- Patient transport
- Acute respiratory distress syndrome
- Prior antibiotic exposure
- Age greater than 60 years
- Admitting diagnosis of burns, trauma, or coagulase-negative staphylococcus disease
- Presence of intracranial pressure monitoring

C. Prevention

The Centers for Disease Control (CDC) recently published evidence-based guidelines for the prevention of HAP (Boxes 2 and 3) [6]. Preventive strategies are categorized below into four groups as they pertain to surgical patients.

1. Factors related to endotracheal intubation

The incidence of pneumonia in ventilated patients increases at a rate of 1% to 3% per day of mechanical ventilation [10]. Several studies support the use of noninvasive positive-pressure ventilation to avoid intubation in patients with cardiogenic pulmonary failure [11] and the use of weaning and sedation protocols to reduce the incidence of VAP [12,13]. Avoidance of nasotracheal intubation can prevent the development of VAP through prevention of sinusitis [14–16]. A randomized trial demonstrated that a systematic search for sinusitis in nasotracheally intubated patients decreased incidence of VAP and improved mortality [17].

2. Factors related to mechanical ventilation

Condensate within the ventilator circuit forms at a rate of 30mL/h and is rapidly colonized, serving as a route of contamination [18]. By frequently draining condensate and avoiding routine changes of ventilator tubing, incidence of VAP can be reduced [18–20]. Heat and moisture exchangers for humidification may slightly reduce the incidence of VAP and are more cost-effective while less labor-intensive than conventional methods [21–23]. The type of endotracheal suctioning system (open versus closed) does not affect the incidence of VAP [24–27]. However, with elimination of routine in-line catheter changes, the closed system is more cost-effective [28]. Subglottic suctioning reduces the incidence of VAP and shortens the duration of mechanical ventilation. However, such suctioning does not affect mortality [29–31].

3. Pharmacologic intervention

Medical experts have not reached a consensus on the best method to prevent stress ulcers in patients at risk for HAP. Whether gastric acid suppression leads to increased aerodigestive colonization and higher rates of HAP is yet to be determined [32–36]. Selective gut decontamination involves combination oral and enteral antimicrobials with a short course of parenteral antibiotics to reduce the colonization of the aerodigestive tract with pathogenic microorganisms. Multiple randomized trials demonstrate that selective gut decontamination reduces incidence of VAP and mortality, particularly in surgical and trauma patients. However, this practice has yet to gain acceptance in the United States because of fear that such treatment will lead to antimicrobial resistance [37–41]. Chlorhexidine gluconate oral rinse in critically ill ventilated patients is a safe and effective way to reduce the incidence of VAP [42,43].
Box 2. CDC guidelines for preventing health-care–associated pneumonia

**Staff education**
1. Educate staff on epidemiology and infection-control measures related to HAP.

**Surveillance**
1. Conduct surveillance of HAP in ICU and return data to personnel.
2. Avoid routine culture in absence of clinical suspicion.

**Transmission**
1. Thoroughly clean all equipment to be sterilized.
2. Sterilize equipment properly.
3. Rinse sterile equipment with sterile water if needed.
4. Do not sterilize or disinfect internal machinery of ventilators or anesthesia equipment. However, clean and sterilize reusable components of the system between patients, according to guidelines from the manufacturer.
5. Change breathing circuits, heat moisture exchangers, or humidifier tubing only when visibly soiled or nonfunctioning.
6. Drain tubing condensate away from the patient.
7. Use sterile water with bubbling humidifiers.
8. Between treatments, clean, disinfect, and rinse small-volume nebulizers with sterile water.
9. Use sterile fluid for nebulization and dispense it aseptically.
10. Use aerosolized medication in single-dose vials when possible.
11. When using mist tents, replace all disposable parts between each use on different patients with sterilized or highly disinfected equipment.
12. Subject mist-tent nebulizers, reservoirs, and tubing used on the same patient to daily low-level disinfection or pasteurization followed by air-drying.
13. Subject resuscitation bags, respirometers, and ventilator thermometers to sterilization or high-level disinfection between uses on different patients.
14. Do not use large-volume room-air humidifiers unless they can be sterilized or subjected to high-level disinfection.
15. Adhere to standard precautions.
16. Perform and change tracheostomy tube under aseptic conditions.
17. If an open-system suction catheter is used for suctioning of respiratory tract secretions, use a sterile, single-use catheter.
18. Use only sterile fluid to flush the suction catheter.

Modifying host
1. Administer the pneumococcal vaccine to persons 65 years or older, those with chronic medical conditions, all transplant patients, and those in long-term care facilities.
2. Use noninvasive ventilation initially or for weaning from mechanical ventilation whenever feasible to reduce the need for endotracheal intubation.
3. Avoid reintubation.
4. Perform orotracheal, rather than nasotracheal, intubation, unless contraindicated.
5. Use an endotracheal tube with dorsal lumen above the cuff to allow intermittent or continuous suctioning of subglottic secretions.
6. Clear all subglottic secretions before deflating the cuff.
7. Elevate the head of the bed 30–45° unless contraindicated.
8. Routinely verify appropriate placement of the feeding tube.
9. Develop and implement an oral-hygiene program for ICU patients.
10. Preoperatively instruct high-risk surgical patients about the importance of taking deep breaths and ambulating in the immediate postoperative period.
11. Encourage all postoperative patients to take deep breaths and ambulate unless contraindicated.
12. Use incentive spirometry on postoperative patients at high risk for pneumonia.


4. Miscellaneous
Semi-recumbent positioning prevents pneumonia in ventilated patients [44–46]. However, the effectiveness of kinetic therapy and prone positioning in preventing VAP is not firmly established [47,48]. Based on several small randomized clinical trials, the use of epidural anesthesia for perioperative pain control may lead to fewer postoperative cases of pneumonia [49–52]. Data is scant regarding feeding of mechanically ventilated patients, especially surgical patients, at risk for VAP. Today, the evidence does not support the use of small bore feeding tubes, the practice of measuring gastric residual volumes, or postpyloric feeding in the prevention of VAP [53–60].
A. Epidemiology

Catheter-associated urinary-tract infection (CAUTI) is the most common health-care–associated infection worldwide [61]. CAUTIs are problematic...
not only for their attributable morbidity and mortality. They also can har-
or resistant organisms and have been linked to the development of sur-
gical-site infections \[62,63\]. Traditionally, \textit{E coli} has been the most
commonly isolated organism from patients with bacteriuria \[64\]. However,
the most common isolates among patients at our institution are now \textit{Candida}
spp (35\%), \textit{Enterococcus} spp (30\%), and \textit{E coli} (16\%). Pathogenic micro-
ororganisms typically gain access to the urinary system through extraluminal
ascent and less frequently through intraluminal contamination from reflux
through the drainage system.

\textbf{B. Diagnosis and treatment}

Up to 90\% of patients with a CAUTI lack symptoms, making diagnosis
difficult \[65\]. The most accepted definition of a urinary-tract infection is
a urine specimen growing greater than 10^5 colony forming units (CFUs)
per milliliter for noncatheterized patients \[66\]. However, data suggest that
once normally sterile urine is inoculated through an indwelling catheter,
progression to concentrations greater than 10^5 CFU/mL occurs within 72
hours \[67\]. Therefore, many clinicians consider concentrations greater
than 10^3 CFU/mL in a properly collected specimen to be clinically relevant
in a catheterized patient with symptoms \[68\].

Management of CAUTI should include removal or replacement of the
urinary catheter. Because causative microorganisms are often multiresistant,
broad-spectrum antibiotics should be initiated and narrowed accordingly.
Treatment duration for CAUTI has scarcely been addressed. One small
study in women with CAUTI demonstrated single-dose therapy to be as ef-
efective as 10 days of therapy for asymptomatic patients and those with lower-
tract symptoms alone \[69\]. Current Infectious Diseases Society of America
(IDSA) guidelines recommend 3-day treatment for uncomplicated cystitis \[70\].
Therefore, the best treatment for patients with CAUTI is likely between
3 and 14 days, but the exact number of days is yet to be determined. The question
of whether it is useful to treat patients with asymptomatic candiduria is also
unresolved \[71\].

\textbf{C. Prevention}

Eight risk factors are associated with increased rates of CAUTI \[64,116\].
These factors are listed in Box 4.

The most important risk factor for the development of a urinary-tract in-
fecion in a hospitalized patient is the presence of a urinary catheter. Often
such catheters are used inappropriately and remain in place unnoticed by
clinicians \[72\]. Daily prompting by the nursing staff to remove unnecessary
catheters significantly decreases the duration of catheterization and inci-
dence of CAUTI in an ICU setting \[73\]. Other effective strategies to prevent
CAUTI include catheter insertion by properly trained personnel using
aseptic technique and sterile equipment, maintenance of closed sterile drainage, and maintenance of unobstructed urine flow [74].

Through regression analysis, the use of antibiotic therapy was found to be a protective factor in preventing CAUTI [75]. Methodological concerns plague the few randomized trials evaluating prophylactic antimicrobial use and overall do not provide sufficient evidence to support such practice [76–78]. Multiple studies have failed to demonstrate the efficacy of daily regimented metal cleaning, bladder irrigation with antiseptic or antibiotic solution, or the addition of a disinfectant to the collection system in the prevention of CAUTI [79–84]. Alternatives to transurethral catheterization, including condom catheters and suprapubic catheters, may reduce the incidence of CAUTI [85–90]. However, suprapubic catheters are associated with mechanical problems and may be best suited for patients with long-term catheters [85].

Results are mixed with regard to the use of silver-coated urinary catheters. Two large randomized trials demonstrate no benefit with silver-oxide–impregnated catheters in preventing CAUTI [91,92]. Silver-alloy–coated catheters and hydrogel-silver-ion–coated catheters may be beneficial. However, the evidence about the effectiveness of their use is conflicting [93–96].

### Intravascular-catheter–related infections

#### A. Epidemiology

Intravascular-catheter–related infections (CRIs) account for many HAIs acquired by surgical patients. Causative organisms include Coagulase-negative *Staphylococcus* (CNS), *S aureus*, gram negative bacilli and *Candida* spp. MRSA now accounts for 60% of all *S aureus* isolates acquired from ICUs [97]. CRI stems most commonly from contamination of the extraluminal catheter surface with skin flora. The intraluminal surface may also become contaminated from infusates or through hematogenous spread. Risk factors associated with CRIs are given in Box 5:
B. Diagnosis and treatment

Local signs of infection at the catheter site are normally absent. However, in the presence of local or systemic signs of infection, the isolation of more than 15 CFUs or $10^2$ CFUs from a catheter by means of semiquantitative or quantitative culture, respectively, indicates a CRI [98]. Two sets of percutaneous blood cultures may confirm the presence of a bloodstream infection. However, the authors have previously observed that bloodstream infection in the setting of a CRI is not an independent predictor of outcome [99].

Treatment of CRIs involves empiric antibiotic therapy with vancomycin or linezolid that targets the most likely pathogens, CNS and MRSA. In the presence of severe sepsis or immunosuppression, empiric coverage for gram-negative bacilli and *Candida* spp may be necessary. In general, the catheter should be removed and antibiotic treatment continued for 10 to 14 days if blood cultures are positive. For patients with septic thrombosis or endocarditis, treatment should be continued for 4 to 6 weeks. All patients with *S. aureus* CRI with bloodstream infection or associated valvular heart disease should undergo transesophageal echocardiogram in the absence of contraindication to evaluate for vegetations. In uncomplicated cases of CNS infection, the catheter sometimes may be retained with 7 to 14 days of antibiotic treatment and antibiotic lock therapy. Antibiotics need only be continued for 5 to 7 days in patients with uncomplicated CRI caused by CNS if the catheter is removed [98].

C. Prevention

Practices that decrease the rate of CRI include proper hand hygiene and sterile barrier precautions (eg, large drape, hat, mask, and sterile gown) during central venous catheter (CVC) insertion, skin antisepsis with 2%

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**Box 5. Risk factors for intravascular catheter related infections**

<table>
<thead>
<tr>
<th>Factor</th>
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<tbody>
<tr>
<td>Internal jugular catheterization</td>
</tr>
<tr>
<td>Duration of catheterization $\geq 8$ days</td>
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<tr>
<td>Polyvinyl or polyethylene catheters</td>
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<tr>
<td>Frequent manipulations</td>
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<tr>
<td>Improper aseptic technique during insertion</td>
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<tr>
<td>Increasing number of catheter lumens</td>
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<tr>
<td>Povidone-iodine skin antisepsis</td>
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<td>Use of the catheter for TPN</td>
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chlorhexidine gluconate rather than povidone-iodine, and the use of polyurethane catheters rather than polyvinyl chloride or polyethylene catheters [100–103]. The subclavian position is the preferred site for temporary CVCs in preventing CRI when feasible [104]. While catheters impregnated with chlorhexidine and silver sulfadiazine or with minocycline and rifampin have reduced infectious complications, considerations for using such catheters must be balanced against potential risks of antimicrobial resistance [105–107]. CDC guidelines recommend the use of “an antimicrobial or antiseptic-impregnated CVC in adults whose catheter is expected to remain in place more than 5 days if, after implementing a comprehensive strategy to reduce rates of CRI, the CRI rate remains above the goal set by the individual institution” [104]. It is recommended that peripheral catheters be rotated every 72 to 96 hours [104]. However, the routine replacement or rewiring of CVCs does not prevent CRI and is associated with increased mechanical complications [108]. Finally, staff education for all providers inserting, maintaining, and using intravascular catheters cannot be overemphasized in the prevention of CRI. For a complete description of CRI preventative strategies, the reader may refer to CDC Intravascular Catheter Guidelines [104].

Hand hygiene

Semmelweis demonstrated in 1847 that maternal mortality significantly improved following implementation of a hand-hygiene policy [109]. Since that time, numerous studies have demonstrated the cost-effectiveness and efficacy of hand washing in reducing the incidence of HAI [110–112]. Yet, on average, medical professionals adhere to basic hand hygiene recommendations only 40% of the time [109]. Adherence to recommended hand-hygiene practices can be improved through education, feedback, and the use of waterless alcohol-based hand-rub solutions in pocketsize and bedside dispensers [109,113].

Summary

Over the last 30 years the medical community has witnessed a significant reduction in the incidence of bloodstream infections, urinary tract infections, HAPs, and surgical-site infections [114–117]. This improvement is the cumulative result of many of the novel preventative strategies highlighted in this review. In recent years, technological advances have led to better outcomes. Even so, future improvements may still depend on increasing compliance with the simplest interventions, such as correct hand hygiene. Only through a multifaceted approach involving basic science and clinical research, practice improvement, and continuous outcomes
monitoring will the rates of health-care–associated infections be reduced to the absolute minimum.

References


