

Emerging Trends for health care workers in Infection Control Practices

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Abstract

Hospital-acquired infections (HAIs) pose significant risks to patients, leading to increased morbidity, mortality, prolonged hospital stays, and elevated healthcare costs. Recent advancements in infection control practices have focused on reducing HAI incidence through enhanced strategies for hand hygiene, isolation precautions, environmental cleaning, and targeted interventions for specific infections. Hand hygiene remains the most effective method for preventing pathogen transmission, with alcohol-based hand rubbing demonstrating greater efficacy compared to traditional handwashing. Isolation practices, such as contact precautions for multidrug-resistant organisms, have been widely recommended, although their specific contribution to reducing transmission remains unclear. Environmental cleaning has gained attention, with studies highlighting the importance of monitoring cleaning performance and utilizing novel technologies like hydrogen peroxide vapor, ultraviolet light decontamination, and antimicrobial surfaces. Ventilator-associated pneumonia prevention has been addressed through the implementation of care bundles, including head-of-bed elevation, daily sedation interruption, and oral care with chlorhexidine. Central line-associated bloodstream infections have seen substantial reductions following the widespread adoption of prevention bundles focusing on hand hygiene, maximal barrier precautions, and prompt removal of unnecessary lines. Clostridioides difficile infection (CDI) remains a significant challenge, with the emergence of the highly virulent BI/NAP1/027 strain. Strategies to prevent CDI include effective hand hygiene, isolation precautions, and environmental decontamination using chlorine-based disinfectants or novel technologies. Despite progress, challenges persist in improving adherence to evidence-based practices and confirming the impact of new technologies on reducing HAI rates. A multidisciplinary approach encompassing robust infection control policies, antimicrobial stewardship, and healthcare worker education is crucial for sustaining progress in preventing HAIs and ensuring patient safety in hospital settings.

Keywords: Infection Control, health care workers

Introduction

Patients admitted to hospital settings face a significant risk of developing hospital-acquired infections (HAIs), which are linked to higher rates of morbidity, mortality, extended hospital stays, and increased healthcare costs. Recent years have witnessed substantial progress in infection control practices aimed at reducing the incidence of these infections. These advancements encompass improvements in traditional general measures designed to prevent the transmission of pathogens between healthcare workers and patients, as well as among patients themselves, within hospital environments. Specific innovations include enhanced strategies for hand hygiene (HH), the implementation of isolation precautions, and improvements in environmental cleaning protocols. Additionally, novel methods have been introduced to address the prevention of HAIs more broadly, including those related to the use of medical devices (Kollef et al., 2012).

General Prevention

Hand Hygiene

Hand hygiene (HH) remains the most effective and cost-efficient method for preventing the transmission of microorganisms within healthcare settings. Compared to traditional handwashing with soap, alcohol-based hand rubbing has demonstrated greater effectiveness in reducing bacterial counts on the hands. Additionally, alcohol-based hand rubbing has been associated with an increase in HH compliance rates, ranging from 9% to 31%. Its primary advantages include requiring less time for HH compared to soap-and-water washing and the ability to widely distribute HH product dispensers throughout healthcare facilities without the need for sinks, paper towels, or other drying equipment. The Centers for Disease Control and Prevention (CDC) recommends alcohol-based hand rubbing in all clinical situations, except when hands are visibly soiled.

There is ongoing debate regarding the optimal strategies to prevent the transmission of *Clostridium difficile* and norovirus. Although alcohol is ineffective against *C. difficile* spores, studies have not established an association between alcohol-based HH and increased *C. difficile* infection rates. Therefore, except during outbreak scenarios, alcohol-based HH is still recommended for managing patients with *C. difficile*. Similarly, in vitro studies suggest that higher concentrations of ethanol (preferably 95%) are necessary for post-contamination hand treatment with norovirus. However, there is no conclusive evidence supporting alcohol-based disinfectants for norovirus, and the CDC continues to advocate for soap-and-water handwashing during norovirus outbreaks (MacCannell et al., 2011).

Despite its critical importance, HH compliance remains a significant challenge. A recent systematic review highlighted that compliance rates are universally low across healthcare settings, with a median compliance rate of 30% to 40% in hospital units. The review and other studies emphasize the lack of standardized tools and reporting systems for HH compliance, making cross-study comparisons difficult. Numerous investigations have focused on addressing this issue of poor compliance.

Monitoring HH practices and providing feedback are key elements of effective HH programs. Monitoring methods include direct observation by anonymous observers, self-reporting, tracking product usage, and using electronic monitoring systems. Among these, direct observation is the most objective but is also limited by factors such as being time-intensive, costly, and subject to interobserver variability and Hawthorne effects. Direct observation is valuable because it assesses both HH technique and behavioral strengths and weaknesses. Self-reporting, on the other hand, is unreliable due to healthcare workers' tendency to overestimate compliance, and the findings often do not align with observational studies.

Product usage can be monitored manually by measuring the volume or weight of products used over time. While some studies have reported a correlation between high alcohol-based hand rub consumption and higher HH compliance, others have not found such a relationship. A limitation

of measuring product usage is its inability to accurately count the number of HH events. Electronic devices installed in dispensers to monitor product usage have been evaluated in six studies, which demonstrated that these devices can efficiently and accurately count HH events and differentiate usage by dispenser. However, they cannot identify the number of HH opportunities, distinguish between healthcare workers and others using the products, or evaluate HH technique (Boyce, 2011).

Advanced electronic monitoring systems have recently been developed to improve HH compliance. These systems use motion sensors to detect room entry and exit, with corresponding sensors on sinks and alcohol-based dispensers to detect HH events. Electronic prompts remind healthcare workers to perform HH when a sensor detects entry or exit without HH. Although studies have limitations, three investigations using such systems reported improved compliance rates, and one study noted a reduction in nosocomial infections. Personal electronic badges for healthcare workers have also been studied. These badges provide visual or audible reminders for HH after room entry or exit and have demonstrated significant improvements in compliance. Real-time location systems, which use badges that communicate wirelessly with sensors on soap or alcohol dispensers, enable comprehensive HH compliance tracking. Video monitoring systems have also been implemented and shown to be effective in improving HH compliance (Armellino et al., 2012); however, they raise ethical concerns regarding the privacy of both patients and healthcare workers. The primary drawbacks of electronic monitoring systems include high installation and maintenance costs, as well as acceptance challenges among healthcare workers.

Isolation Practices

Infection control measures, including contact precautions in addition to standard precautions, are widely recommended by the Healthcare Infection Control Practices Advisory Committee (HICPAC) and the Society for Healthcare Epidemiology of America for managing multidrug-resistant organisms (MDROs) in healthcare environments. Contact precautions involve healthcare providers wearing gowns and gloves when in contact with the patient or potentially contaminated areas of the patient's surroundings. Droplet precautions are utilized for patients with infections caused by pathogens transmitted through large respiratory droplets ($>5\ \mu\text{m}$ in diameter) that travel distances of 3 to 6 feet (e.g., *Bordetella pertussis* or *Neisseria meningitidis*). Airborne precautions are necessary for pathogens transmitted via smaller particles ($<5\ \mu\text{m}$ in diameter) that remain suspended in the air indefinitely, such as *Mycobacterium tuberculosis* or the varicella-zoster virus. These measures are integral to infection control practices for addressing highly communicable, virulent, or multidrug-resistant pathogens.

However, the use of contact precautions for MDROs, such as methicillin-resistant *Staphylococcus aureus* (MRSA), has become controversial due to their widespread prevalence in the community. Concerns include the difficulty in accurately identifying colonized individuals and the potential for overuse to cause complacency among medical staff. Furthermore, there are no randomized clinical trials directly comparing the efficacy of standard precautions to contact precautions for

MDROs. Multiple infection control measures are often implemented alongside contact precautions to prevent MDRO transmission, making it difficult to assess the specific contribution of contact precautions (Bearman & Stevens, 2012).

For MRSA, several strategies have been studied, but the most effective approach remains unclear. One study demonstrated that universal MRSA screening for all hospital patients, followed by contact precautions, significantly reduced the incidence of MRSA bacteremia both in hospital units and facility wide. Another study found that screening all patients upon hospital admission, followed by decolonization and contact precautions, led to reductions in MRSA-related diseases during hospitalization and within 30 days post-discharge. Conversely, a separate investigation found no impact of universal screening on hospital-acquired MRSA infections in a surgical department.

Two recent large trials produced conflicting findings. A prospective, cluster-randomized trial supported by the NIH in adult hospital units found no significant effect of active MRSA and vancomycin-resistant *Enterococci* (VRE) surveillance combined with expanded barrier precautions on colonization or infection rates (Huskins et al., 2011). In contrast, a quality improvement initiative across Veterans Affairs (VA) hospitals demonstrated that the use of a "MRSA bundle," which included active surveillance and contact precautions for colonized patients, decreased healthcare-associated MRSA transmission and infections in both hospital unit and non-unit settings (Jain et al., 2011). A notable distinction between these studies was the method of MRSA identification. The VA study employed polymerase chain reaction (PCR) testing with a turnaround time of less than one day, whereas the NIH-supported trial used culture-based testing with an average turnaround time of 5.2 days. It is unclear whether the difference in diagnostic timing influenced the outcomes. Furthermore, the VA study reported a comparable decline in VRE transmission without targeted VRE-specific interventions, suggesting that reductions in MRSA transmission may have resulted from general infection control measures, such as improved hand hygiene (HH) compliance and care bundles. Using data from the VA MRSA initiative, a Dutch research group applied mathematical modeling and concluded that universal screening and isolation strategies only minimally reduced infections, with an estimated reduction of 1%-4% in hospital units and 3%-6% in non-unit settings (Gurieva et al., 2012).

Evidence supporting contact precautions for controlling multidrug-resistant gram-negative bacteria is limited. One study examined the impact of contact precautions on nosocomial transmission of extended-spectrum β -lactamase (ESBL)-producing organisms in a non-outbreak context. In this quasi-experimental study, patients colonized or infected with ESBL organisms were placed on contact precautions. During the seven-year study period from 1999 to 2005, nosocomial ESBL cases increased from 0.03 to 0.05 per 1,000 patient days ($P = .002$), but there was no significant change in hospital unit-acquired ESBL cases (0.08 vs. 0.12 per 1,000 unit days, $P = .44$). Compliance with contact precautions was 88% based on three months of direct observation; however, compliance among physicians was only 25%, and HH compliance for patients not on contact precautions was 44%. Regional ESBL incidence also increased from 1.32

to 9.28 per 100,000 population ($P < .0001$). Although third-generation cephalosporin use remained stable, piperacillin/tazobactam, fluoroquinolone, and total antibiotic usage increased during the study. The rise in nosocomial ESBL cases was attributed to inadequate adherence to contact precautions, poor HH compliance, and increased antibiotic consumption. The authors concluded that while contact precautions contributed to outbreak prevention, they did not affect nosocomial ESBL incidence.

Environmental Cleaning

Evidence increasingly supports that healthcare-associated pathogens, including MRSA, VRE, *Clostridioides difficile* (*C. difficile*), *Acinetobacter* species, *Pseudomonas aeruginosa*, and norovirus, are transmitted to patients via contaminated environmental surfaces (Otter et al., 2011). Inadequate cleaning of these surfaces perpetuates the transmission of pathogens to subsequent patients due to the organisms' ability to persist on inanimate surfaces shed by prior occupants. As patients are the primary source of environmental contamination, surfaces proximal to them are most frequently contaminated. These high-touch surfaces include bedrails, the bed surface, television controls/nurse call buttons, and supply carts. Studies indicate that high-touch surfaces are often neglected during routine cleaning, presenting significant opportunities for improving cleaning practices.

Programs that monitor cleaning performance and provide housekeepers with direct feedback have demonstrated improvements in the thoroughness of hospital environmental hygiene. One large multicenter study conducted in 27 acute care hospital settings showed that the thoroughness of cleaning high-touch surfaces increased from a baseline of 49.5% to 82% following an intervention. In this study, a transparent, fluorescent, and easily cleanable gel was applied to high-touch surfaces, and housekeepers received repeated feedback from managers regarding their cleaning performance in patient rooms. Other methods to evaluate cleaning performance include direct observation, microbial culturing, and measuring organic adenosine triphosphate levels on surfaces after terminal cleaning. Although evidence regarding the effectiveness of these monitoring methods in reducing pathogen transmission and healthcare-associated infections is currently unavailable, HICPAC recommends monitoring the cleaning performance of high-touch surfaces.

Several new technologies have been developed to enhance environmental decontamination methods. Among the most promising are room sterilization with hydrogen peroxide vapor, ultraviolet (UV) light decontamination for terminal cleaning, and ultramicrofibers (UMFs) combined with copper-based biocides for daily cleaning. However, these technologies do not prevent subsequent microbial recolonization of surfaces. To address this limitation, antimicrobial surface materials have been developed to provide sustained reductions in bioburden on high-touch surfaces.

Hydrogen peroxide has been studied as a vapor or dry mist for environmental decontamination in five investigations. Three of these studies focused on its efficacy against MRSA, one on *C. difficile*, and another on multiple pathogens, including MRSA, VRE, and gentamicin-resistant gram-

negative rods. All studies reported significant reductions in environmental contamination with the targeted pathogens. Hydrogen peroxide vapor's role as an infection control measure was further evaluated in four additional studies. These studies demonstrated its utility in ending an outbreak of *Serratia* species in a neonatal unit, controlling a polyclonal MRSA outbreak in a surgical ward, significantly reducing *C. difficile* infection rates in one institution, and eradicating persistent MRSA contamination in a surgical ward. While hydrogen peroxide vapor does not appear to damage medical instruments, it requires sealing the room during treatment for the safety of patients and healthcare workers. One study found that the mean time from room vacancy to readiness for the next patient was 270 minutes with hydrogen peroxide vapor decontamination, compared to 67 minutes for cleaning with bleach. Additional drawbacks include the technology's high cost and challenges in adequately sealing certain hospital rooms.

UV light decontamination is performed using mobile, fully automated devices that utilize UV-C irradiation to eliminate pathogens. Three studies evaluated the use of UV light for environmental decontamination (Boyce et al., 2011). All three showed significant reductions in contamination by MRSA, VRE, and *C. difficile* on environmental surfaces, and one also demonstrated reduced contamination by *Acinetobacter* species. Since UV light does not penetrate most substances, thorough pre-cleaning by housekeeping staff is required to remove visible contamination. These systems do not require sealing patient rooms, but staff must vacate the area during the decontamination process to prevent potential optical damage from UV light exposure. Further research is necessary to determine whether UV light decontamination reduces MRSA, VRE, and *C. difficile* colonization and infection rates in hospitalized patients. Additionally, the cost-effectiveness of the technology needs evaluation, considering the requirement for specialized staff to operate the equipment and its impact on room turnover times.

Compared to conventional cotton string mops, microfiber (MF) mops have proven more effective at disinfecting hospital surfaces. Ultramicrofibers (UMFs) are finer than standard MF and remove particles through static attraction and capillary action. UMF mops are designed for use with low water volumes, eliminating the need for detergents or biocidal solutions. One study evaluated the effectiveness of UMFs combined with a copper-based biocide for daily cleaning in non-hospital unit settings. The study compared UMFs used with water against UMFs impregnated with a copper biocide solution (CuWB50). Overall, there was a 56.3% reduction in total viable count levels one hour after cleaning with UMF + CuWB50, compared to a 30% reduction with UMF + water. Further research is required to assess whether UMFs with copper-based biocides can significantly reduce healthcare-associated infection rates.

Self-Disinfecting Antimicrobial Surfaces

Recent interest in self-disinfecting antimicrobial surfaces has emerged due to their potential to prevent recolonization by microorganisms. Copper and silver ions have garnered particular attention for their direct antimicrobial properties, leading to the development of copper- and silver-coated surfaces. In a recent study presented in abstract form, patients admitted to hospital units in

three different facilities were randomly assigned to rooms with either standard surfaces or copper-coated surfaces. This study observed a significant reduction in healthcare-associated infections among patients in rooms with copper surfaces compared to standard rooms (8.95 vs. 15.16 per 1000 patient days; $P = .00003$). Additionally, the rate of MRSA or VRE acquisition was significantly lower in copper rooms compared to standard rooms (6.12 vs. 8.8 per 1000 patient days; $P = .03$). In another crossover study conducted in a medical ward, microbial counts were measured on frequently touched items made from either standard materials or copper alloys (Karpanen et al., 2012). Eight out of fourteen items showed significantly lower microbial counts on copper alloy surfaces compared to standard materials. Reductions were noted specifically for VRE and coliforms but not for MRSA or *C. difficile*. While these findings are promising, clinical data on the overall impact of such antimicrobial surfaces are not yet available.

Antimicrobial Bathing

Although environmental contamination with multidrug-resistant organisms (MDROs) is a concern, colonized patients remain the primary reservoir for these pathogens in hospital settings. Reducing this reservoir may decrease the risk of nosocomial transmission and enhance patients' resistance to colonization. Consequently, several studies have evaluated daily bathing with the skin antiseptic chlorhexidine. Despite differences in bathing protocols and study endpoints, the combination of chlorhexidine baths with nasal mupirocin has been associated with reduced MRSA acquisition rates in hospital settings and a decrease in MRSA-related nosocomial infections. Similarly, chlorhexidine bathing has been linked to reductions in central line-associated bloodstream infections (CLABSIs) in hospitals, although it does not appear to affect secondary bloodstream infections, ventilator-associated pneumonias (VAPs), catheter-associated urinary tract infections (CAUTIs), or *C. difficile* infections (CDIs). Another study found significant reductions in MRSA and VRE acquisition and related bloodstream infections following the implementation of daily chlorhexidine bathing in hospital units. A study examining the impact of chlorhexidine baths on VAP rates demonstrated a significant reduction in MRSA-associated VAP, though there was no overall reduction in VAP rates compared to bathing with soap and water. In contrast, a surgical unit study found no significant difference in CLABSI rates between chlorhexidine baths and soap and water. In this study, gram-negative bacilli were more frequently implicated in CLABSIs among the chlorhexidine group, whereas coagulase-negative staphylococci and enterococci were predominant in the soap and water group. The authors speculated that open abdominal wounds might allow translocation of bacteria from the gut into the bloodstream, potentially leading to misclassification of bloodstream infections as CLABSIs rather than secondary bloodstream infections.

Modern Trends in Prevention of Ventilator-Associated Pneumonia (VAP)

Ventilator-associated pneumonia (VAP) is defined as a parenchymal lung infection occurring either during mechanical ventilation or within 48 hours after its discontinuation. VAP is a leading cause of nosocomial infections in hospitals, affecting approximately 10–20% of patients receiving

mechanical ventilation for more than 48 hours. It has been associated with increased morbidity, prolonged mechanical ventilation, extended hospital stays, and elevated healthcare costs. Although the mortality attributable to VAP remains debated, a systematic review of randomized trials on VAP prevention estimated it to be approximately 9%.

These studies typically utilize the CDC National Healthcare Safety Network (NHSN) surveillance criteria to diagnose VAP. However, the accuracy of this information is challenging to establish due to ambiguities in the NHSN criteria. Several conditions commonly present in hospitalized patients, such as pulmonary edema, pulmonary contusion, hypersensitivity drug reactions, systemic inflammatory response syndrome-associated lung damage, or pulmonary hemorrhage, can mimic the clinical features of VAP. A recent study highlighted the limitations of the current NHSN definition, showing only 62% concordance in VAP diagnosis among trained infection preventionists. Recognizing these challenges, the CDC has proposed a new surveillance definition algorithm for ventilator-associated events (VAEs). This algorithm, which includes VAP among other conditions, requires a minimum of three calendar days on a ventilator and relies on objective clinical data without including chest radiograph findings.

Despite diagnostic uncertainties, the adverse health and economic impacts associated with VAP underscore the importance of prevention strategies. Many of these strategies are incorporated into the "ventilator bundle" promoted by the Institute for Healthcare Improvement (IHI). The initial IHI ventilator bundle, proposed in 2004, included the following interventions: (1) elevating the head of the bed, (2) thromboembolism prophylaxis, (3) stress ulcer prophylaxis, and (4) daily sedative interruption with daily assessment of readiness to wean from mechanical ventilation. In May 2010, IHI added daily oral care with chlorhexidine to the bundle. A cross-sectional survey of 415 hospital units from 250 U.S. hospitals showed that the ventilator bundle is widely used, though not always implemented effectively. Strict adherence to infection-specific elements, including head-of-bed elevation, daily "sedation vacations," and daily readiness-to-extubate assessments, was associated with significant reductions in VAP rates. Another study conducted in a single medical-surgical hospital unit found that implementation of the IHI ventilator bundle led to a significant decrease in VAP rates (Morris et al., 2011).

Analysis of Ventilator Bundle Components

Research on the individual components of the ventilator bundle has been relatively limited. Recently, a meta-analysis and a systematic review examined the impact of head-of-bed elevation. Interestingly, despite analyzing the same randomized controlled trials, these reviews reached differing conclusions. The meta-analysis found that patients positioned semirecumbently at a 45° angle had a significantly lower incidence of clinically diagnosed VAP compared to patients positioned supinely. Conversely, the systematic review determined that the effectiveness or harm of 45° head-of-bed elevation regarding clinically suspected or microbiologically confirmed VAP remained uncertain (Niël-Weise et al., 2011). Daily sedation holidays and assessments of readiness for extubation have been associated with reduced durations of mechanical ventilation, potentially

lowering the risk of VAP as a secondary effect. Two meta-analyses and a large randomized controlled trial reported that oral decontamination with chlorhexidine significantly decreased VAP rates.

Subglottic Secretion Drainage (SSD)

A key factor in the development of VAP is the aspiration of subglottic secretions that pass around an endotracheal tube cuff, introducing microorganisms into the lower respiratory tract. Subglottic secretion drainage (SSD) aims to prevent this by using a specially designed endotracheal tube with an additional dorsal lumen that opens just above the cuff, facilitating the removal of secretions. A meta-analysis of randomized controlled trials comparing SSD with standard endotracheal tube care in mechanically ventilated patients found that SSD effectively reduced early-onset VAP in patients requiring more than 72 hours of mechanical ventilation. A recent multicenter randomized study conducted after the meta-analysis also demonstrated that intermittent SSD significantly decreased both early-onset (occurring within 5 to 7 days of mechanical ventilation) and late-onset VAP (occurring after 5 to 7 days of mechanical ventilation) in patients ventilated for more than 48 hours. In this study, subglottic secretions in the experimental group were aspirated hourly using a 10-mL syringe. Although a significant reduction in VAP was observed, no notable differences were found in mechanical ventilation duration or hospital mortality between the groups.

Silver-Coated Endotracheal Tubes

Silver ions are known to inhibit microbial colonization of surfaces, and their application to endotracheal tubes has been evaluated for its impact on VAP rates. A large multicenter randomized study demonstrated that patients receiving silver-coated endotracheal tubes had significantly lower rates of microbiologically confirmed VAP compared to those with uncoated tubes (4.8% vs. 7.5%; $P = .03$). However, no significant differences were observed in the duration of intubation, hospital stay, or mortality between the two groups.

Endotracheal Tube Cuff Material

Another strategy to prevent the passage of subglottic secretions around endotracheal tube cuffs involves redesigning the cuff material. Ultrathin polyurethane cuffs have been developed to minimize folds and bends when inflated. Three studies have investigated the effect of polyurethane-cuffed endotracheal tubes (PUC-ETTs) on VAP rates. In the first study, PUC-ETTs were used alongside SSD, resulting in a significant reduction in both early-onset (3.6% vs. 10.7%; $P = .02$) and late-onset VAP (9.5% vs. 26.7%; $P = .01$) compared to conventional polyvinyl chloride endotracheal tubes (PVC-ETTs). Since SSD was part of the experimental group, the individual contributions of each intervention could not be determined. Another single-center randomized controlled trial comparing PUC-ETTs with PVC-ETTs in cardiac surgery patients found that the incidence of early postoperative pneumonia was significantly lower in the polyurethane group (adjusted odds ratio: 0.31; 95% confidence interval [CI]: 0.13–0.77). More recently, a retrospective interrupted time series analysis showed a significant reduction in VAP

rates when conventional PVC-ETTs were replaced with PUC-ETTs. VAP rates decreased from 5.3/1000 ventilator days to 2.8/1000 ventilator days during the intervention period ($P = .013$) (Miller et al., 2011).

Cuff Pressure Monitoring

Maintaining adequate cuff pressure is another strategy believed to reduce VAP rates by limiting the aspiration of subglottic secretions. A study evaluated an automated, validated device for continuous regulation of tracheal tube cuff pressure and its effect on VAP prevention. The automated group experienced significantly fewer instances of low cuff pressure compared to the control group (0.7% vs. 45.3%; $P < .001$). However, there was no significant difference in VAP rates between the two groups.

Continuous Lateral Rotation Therapy (CLRT)

Prolonged immobilization associated with mechanical ventilation is recognized as a risk factor for VAP. Continuous lateral rotation therapy (CLRT) utilizes specialized beds that allow patients to rotate longitudinally between lateral positions, covering total angles ranging from 60° to 164°. Two meta-analyses reviewed the impact of CLRT on VAP rates. Both concluded that definitive recommendations could not be made due to poor methodological quality and inconsistent results across studies. A recent randomized controlled trial, however, found that CLRT was associated with reduced VAP rates (11% vs. 23%; $P = .048$) and shorter durations of mechanical ventilation and hospital stays in the experimental group.

Saline Instillation Prior to Endotracheal Suctioning

A recent single-center randomized study examined the impact of saline instillation before suctioning on VAP rates in patients requiring mechanical ventilation for over 72 hours. The findings revealed that patients in the saline group experienced significantly lower rates of microbiologically confirmed VAP compared to the control group (10.8% vs. 23.5%; $P = .008$). The study's author suggested that the observed benefits could be attributed to the stimulation of the natural cough reflex, thinning of secretions, increased removal of secretions during suctioning, and disruption of the biofilm on the endotracheal tube.

Multimodality Chest Physiotherapy

The effect of multimodality chest physiotherapy on VAP incidence was evaluated in a recent clinical trial. The control group received standard chest physiotherapy consisting of manual hyperinflation and suctioning twice daily, while the experimental group underwent additional positioning and chest wall vibrations. The study reported a significant reduction in clinical pulmonary infection scores in the experimental group compared to the control group (3.4 vs. 1.9; $P < .001$), indicating a decrease in VAP occurrence. However, the study's limitations included the exclusion of many typical hospital patients.

Positive End-Expiratory Pressure (PEEP)

The prophylactic use of PEEP in nonhypoxemic patients requiring mechanical ventilation was investigated in a multicenter randomized controlled trial. Although the primary outcome, hospital mortality, showed no significant difference between the experimental and control groups, the experimental group demonstrated a significant reduction in VAP rates as a secondary outcome (risk ratio [RR]: 0.37; 95% CI: 0.15–0.84; $P = .017$). This group received mechanical ventilation with 5 to 8 cm H₂O of PEEP, whereas the control group did not receive PEEP.

Tracheotomy

The impact of early tracheotomy (6–8 days post-intubation) versus late tracheotomy (13–15 days post-intubation) on VAP rates was investigated in a recent randomized controlled trial. The study found no statistically significant difference in VAP incidence between the early and late tracheotomy groups (14% vs. 21%; $P = .07$). The authors concluded that early tracheotomy should not be routinely recommended, as over one-third of patients in the early tracheotomy group experienced adverse events related to the procedure, and there was no significant difference in VAP rates.

Patient Positioning During Transport

Several studies have identified an association between frequent patient transport and an increased incidence of VAP. The proposed mechanism involves a heightened risk of aspiration of subglottic secretions due to positional changes during transport. Interventions such as suctioning oral secretions before transport and ensuring the head of the bed remains elevated during transport may potentially mitigate this risk, though these strategies have not been evaluated in clinical trials.

Modern Trends in Prevention of CLABSI

According to the CDC's National Healthcare Safety Network (NHSN) definition, CLABSI is identified by the recovery of a pathogen from a blood culture in a patient with a central line at the time of infection or within 48 hours of the positive blood culture, without evidence of infection at another site. CLABSIs are associated with longer hospital stays, increased costs estimated at up to \$29,000 per episode, and mortality rates ranging from 0% to 35%. In 2006, the publication of the Keystone study demonstrated that implementing a standardized CLABSI prevention bundle could substantially reduce CLABSI rates across the state of Michigan. This bundle includes five key interventions: hand hygiene, maximal barrier precautions during catheter insertion, chlorhexidine skin antisepsis, optimal catheter site selection, and daily assessment of line necessity with prompt removal of unnecessary lines. Following the widespread adoption of this bundle, U.S. hospitals observed approximately 25,000 fewer CLABSI cases in 2009 compared to 2001, representing a 58% reduction. This decline in hospital-acquired CLABSIs alone has been estimated to save \$1.8 billion in costs and 27,000 lives (Centers for Disease Control and Prevention (CDC), 2011).

Other interventions are available for reducing CLABSI rates but are currently recommended by the CDC only for settings with persistently high CLABSI rates despite implementing the prevention bundle. These include antimicrobial-coated central venous catheters, daily chlorhexidine bathing, chlorhexidine-impregnated sponge dressings, and anti-infective lock therapy. Anti-infective lock therapy is primarily aimed at long-term catheters and is not addressed in this review.

Modern Trends in Prevention of CDI

Clostridioides difficile infection (CDI) remains the leading cause of nosocomial infectious diarrhea, associated with increased mortality, prolonged hospital stays, and elevated healthcare costs in hospital settings (Centers for Disease Control and Prevention (CDC), 2012). A recent survey of 648 hospitals in the United States reported a point prevalence of CDI at 13.1 per 1000 inpatients. Additionally, a study in community hospitals in the southeastern United States found that the incidence of hospital-acquired CDI has exceeded that of hospital-acquired MRSA infections. According to a recent systematic review, the annual healthcare costs attributed to CDI in the United States range from \$433 to \$797 million.

The rising incidence of CDI has been linked to the dissemination of a specific *C. difficile* strain, BI/NAP1/027, which is associated with severe disease, increased mortality, and epidemic outbreaks. The reasons behind its widespread transmission are not entirely clear, but evidence suggests enhanced virulence due to elevated production of *C. difficile* toxins A and B, along with resistance to fluoroquinolone antibiotics, which may have previously inhibited its prevalence (He et al., 2013).

Several risk factors are associated with CDI, including advanced age, antibiotic use, proton pump inhibitors, chemotherapy, recent hospitalization, multiple comorbidities, HIV infection, glucocorticoid therapy, hemodialysis, bone marrow or solid organ transplantation, inflammatory bowel disease, abdominal surgery, and enema use (Loo et al., 2011). Moreover, a recent study identified prior room occupancy by a patient with CDI as a significant risk factor for CDI acquisition. Among patients who developed CDI post-admission, 4.6% had prior room occupants without CDI, while 11.0% ($P = .02$) had prior occupants with CDI (Shaughnessy et al., 2011). Another crucial risk factor in hospital settings is increased colonization pressure, defined as a higher number of patients with CDI in the same unit (Ajao et al., 2011).

Strategies to Prevent CDI

The primary sources of *C. difficile* exposure in hospital environments are the contaminated hands of healthcare workers and contaminated surfaces. Effective infection control practices are vital in mitigating transmission. In the context of hand hygiene (HH), evidence indicates that washing with soap and water is more effective at removing *C. difficile* spores compared to alcohol-based solutions, as alcohol has no activity against spores. However, clinical studies have not demonstrated a correlation between alcohol-based HH practices and CDI incidence. Thus, except

during outbreak settings, routine use of alcohol-based hand rubs remains recommended for managing *C. difficile* patients.

Isolation precautions for managing patients with CDI include wearing gloves and gowns and isolating patients in private rooms. While gloves have proven effective in preventing the transmission of *C. difficile* spores, the efficacy of gowns is less well studied. Beyond infection control, reducing inappropriate antibiotic use and implementing antimicrobial stewardship programs have been linked to reductions in CDI incidence.

Environmental Decontamination

Conventional hospital cleaning agents, such as quaternary ammonium-based detergents, are ineffective against *C. difficile* spores and may even promote sporulation. Chlorine-based disinfectants, on the other hand, are effective in eliminating *C. difficile* spores. Studies have demonstrated that 10% sodium hypochlorite solutions reduce environmental contamination with *C. difficile* spores and are associated with lower CDI rates. However, higher concentrations of sodium hypochlorite are not recommended due to their strong odor, potential to corrode equipment, and risk of causing respiratory discomfort among staff.

Innovative strategies for environmental decontamination include the use of hydrogen peroxide vapor, UV light technology, and copper-coated surfaces. Studies have shown that hydrogen peroxide vapor significantly reduces *C. difficile* contamination. Similarly, three studies have reported significant reductions in *C. difficile* contamination with the use of UV light technology. Additionally, copper alloy surfaces have demonstrated a substantial decrease in the survival of *C. difficile* vegetative cells and spores compared to standard stainless-steel surfaces commonly used in hospitals. However, none of these novel strategies have been evaluated in clinical trials, and further research is necessary to determine whether they effectively reduce nosocomial CDI rates.

Conclusion

Hospital-acquired infections (HAIs) remain a significant challenge in healthcare settings, posing risks of increased morbidity, mortality, and healthcare costs. Advances in infection control practices have led to the development of innovative strategies aimed at reducing the incidence of HAIs. Enhanced hand hygiene compliance improved environmental cleaning protocols, and targeted isolation practices have demonstrated efficacy in limiting the spread of multidrug-resistant organisms and other pathogens. Novel approaches, such as antimicrobial-coated devices, chlorhexidine-based interventions, and the implementation of care bundles for specific conditions like ventilator-associated pneumonia (VAP) and central line-associated bloodstream infections (CLABSI), have contributed to meaningful reductions in infection rates.

Despite these advancements, challenges persist, including the emergence of highly virulent strains such as *Clostridioides difficile* BI/NAP1/027 and the ongoing need to improve adherence to evidence-based practices. New technologies, such as hydrogen peroxide vapor, ultraviolet light

decontamination, and antimicrobial surfaces, hold promise but require further clinical evaluation to confirm their impact on reducing nosocomial infection rates.

A multidisciplinary approach that includes robust infection control policies, antimicrobial stewardship, and education for healthcare workers is essential for sustaining progress in preventing HAIs. Continued research and innovation, coupled with systematic implementation of best practices, are critical to overcoming the evolving challenges in infection control and ensuring the safety and well-being of patients in hospital settings.

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