18 Vertical Versus Horizontal Infection Control Interventions

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Vertical Versus Horizontal Infection Control Interventions

Healthcare-associated infections (HAIs) are often preventable diseases that are not only a major concern for patient safety but also represent a major economic burden on a nation's healthcare system [1, 2]. These include, but are not limited to, surgical site infections (SSIs), central line-associated bloodstream infections (CLABSIs), catheter-associated urinary tract infections (CAUTIs), and infections (BSIs) caused by multidrug-resistant organisms (MDROs) such as methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), carbapenem-resistant *Enterobacteriaceae* (CRE), carbapenem-resistant *Acinetobacter baumannii* (CRAB), and *Candida auris* [3, 4]. Severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has recently emerged as a pathogen of epidemiologic importance, causing a pandemic and overwhelming healthcare facilities worldwide [5]. Reducing the spread of infection is the key goal of infection prevention programs and numerous strategies such as hand hygiene, contact precautions, and chlorhexidine bathing have been implemented to achieve this. Some of these targeting specific microorganisms are called "vertical" strategies, while others aim to reduce infections caused by multiple pathogens simultaneously and are known as "horizontal" strategies (Fig. 18.1) [6].

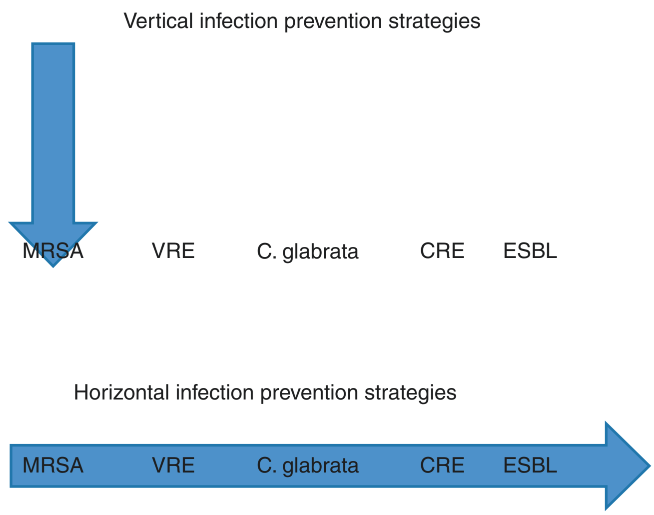

Fig. 18.1 Vertical vs. horizontal infection prevention strategies. Edmond and Wenzel [6]

Compare and Contrast Vertical and Horizontal Strategies

Patients are at risk for exposure to organisms such as MRSA, VRE, and CRE during hospital admissions and can become colonized with them. They may go on to develop infections with these organisms or transmit them to other patients. A vertical strategy targets patients colonized or infected with a specific microorganism and aims to decrease the number of infections caused by this single pathogen. On the contrary, the horizontal approach is a more holistic strategy adopted to reduce infections caused by all microorganisms sharing a common means of transmission. As a result, the horizontal approach is generally a utilitarian strategy, while the vertical strategy supports exceptionalism by prioritizing the eradication of specific pathogens [6]. Resource utilization for vertical strategies typically surpasses horizontal strategies. Horizontal strategies are more patient-centric strategies, in so much that patients benefit from prevention of all infections simultaneously, not just those caused by specific micro-

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Table 18.1 Vertical vs. horizontal infection control strategies [5]

	Horizontal	Vertical
Focus	Population-based	Pathogen-based
Population	Universal	Selective or universal
Resource costs	Relatively low	Usually high
Philosophy	Utilitarian	Exceptionalism
Values favored	Patient	Hospital, infection prevention experts
Temporal focus	Present, future	Present

organisms. In addition, vertical strategies are short term as efforts are made to prevent the spread of infections caused by a specific pathogen at a given point in time, while horizontal strategies, by virtue of their larger scale, are not only relevant to a hospital's current situation but may play a greater role in the long-term prevention of infections as well. Finally, both types differ in the types of infection–prevention approaches used: examples of vertical programs include active surveillance for MRSA and vaccination against specific pathogens, whereas horizontal strategies encompass implementation of measures such as hand hygiene, bathing patients with antiseptics such a chlorhexidine gluconate (CHG), antimicrobial stewardship, and environmental disinfection to name a few [6]. Both strategies have been used to prevent infections and many studies have been conducted to determine their effectiveness (Table 18.1).

Evidence for Vertical Infection Control Strategies

Vertical strategies are mostly based on the results of active surveillance and testing (AST), a strategy aimed at reducing colonization of various anatomic sites by pathogens and thereby reducing infection and transmission of these by identifying carriers. This approach has been most widely implemented for the eradication of MRSA, VRE, and CRE and numerous studies have been conducted to elucidate the effects of AST with or without additional decolonization measures [7, 8].

Methicillin-Resistant *Staphylococcus aureus*

The overall incidence of MRSA infections has increased significantly since its emergence in the 1960s. Additionally, due to the virulence of community-acquired MRSA strains and their growing contribution to HAIs, MRSA identification and eradication has been identified as an important infection control strategy [9]. Intensive care units (ICUs) are considered high-risk settings for the transmission of MDROs such as MRSA and multiple studies have been conducted to determine the impact of infection prevention strategies on the incidence of HAIs in these units. Huskins and colleagues conducted a cluster-randomized trial in adult ICUs to evaluate the effect of active surveillance and isolation for MRSA and VRE compared with standard practice. During a 6-month study period, 5434 admissions to 10 ICUs were assigned to the intervention arm and 3705 admissions to 8 ICUs were assigned to the control arm. The results of this study did not demonstrate any benefit of AST and isolation for infection prevention as the difference in the mean incidence of MRSA and VRE colonization and infection-related events per 1000 patient days between the two groups was not statistically significant (40.4 ± 3.3 and 35.6 ± 3.7 in the intervention and control groups, respectively; $p = 0.35$) [10]. Similarly, a comparative effectiveness review performed by Glick and colleagues found insufficient evidence for the use of targeted MRSA screening as a sole infection prevention strategy [11]. Zafar and colleagues conducted a prospective observational study to assess the prevalence of nasal colonization among patients with community-associated MRSA infection admitted to a 600-bed urban academic center between 2004 and 2006. A total of 51 patients underwent nasal swab cultures and only 41% were found to have nasal colonization with MRSA. The results of this study demonstrated that MRSA infections may occur in a high percentage of patients without nasal MRSA carriage which argues against the utility of vertical infection prevention strategies given their narrow focus [12]. Moreover, MRSA screening does not have an impact on other organisms such as VRE and CRE (as opposed to many horizontal infection control strategies that impact multiple organisms simultaneously) [9].

Given the widespread use of mupirocin for MRSA decolonization, emerging resistance is an area of major concern. Mupirocin is a protein synthesis inhibitor which acts by inhibiting bacterial isoleucyl-tRNA synthetase. *S. aureus* strains may harbor alterations in the isoleucyl-tRNA synthetase *ileS* gene which confers low-level resistance (MIC = 8–256 μg/ml) or *mupA* gene which is associated with high-level resistance (MIC ≥ 512 μg/ml) [13]. Fritz and colleagues conducted a study to determine the prevalence of high-level mupirocin resistance among 1089 pediatric patients admitted with skin and soft tissue infections. Cultures were obtained from axillae, anterior nares, and inguinal folds and 483 patients were found to be colonized with *S. aureus*. Of these, 23 isolates (2.1%) carried the *mupA* gene. A total of 408 patients, including four patients colonized with *S. aureus* harboring a *mupA* gene, underwent nasal decolonization with twice daily application of mupirocin for 5 days (with or without antimicrobial baths) and 258 underwent daily CHG bathing for 5 days. Patients were followed with colonization cultures for up to 12 months. Among the patients carrying mupirocin-resistant *S. aureus*, 100%

remained colonized at 1 month compared to 44% of the patients who were carriers of mupirocin-sensitive *S. aureus* ($p = 0.041$) [13].

Carbapenem-Resistant *Enterobacteriaceae* and *Acinetobacter baumannii*

Carbapenems are an important antimicrobial class given their activity against gram-negative organisms with Amp-C-mediated β(beta) –lactamases or extended-spectrum β(beta)–lactamases (ESBLs) [14]. Selection of carbapenem-tolerant *Enterobacteriaceae* was uncommon in the United States in the 1990s, prior to the recognition of novel β(beta)–lactamases with carbapenem-hydrolyzing activity. *Klebsiella pneumoniae* carbapenemase (KPC) is the most commonly identified carbapenemase in the United States. Others such as the Metallo-β(beta)-lactamases are more common in other parts of the world. The Centers for Disease Control and Prevention (CDC) currently recommend point-prevalence surveys to identify CRE carriers in units where infections caused by these organisms have been identified over the past 6–12 months. The recommendations to prevent their transmission include implementation of hand hygiene, contact precautions, and testing contacts of CRE patients. Infection prevention personnel should be promptly notified regarding the detection of CRE and additional measures such as skin decolonization may be employed if felt necessary [15].

CRE are a major challenge given the frequency of infections caused by these organisms as well as the associated mortality which may be as high as 50% among ICU patients [16]. Patel and colleagues conducted two matched case-control studies to determine the epidemiology of CRE infections and determine risk factors and clinical outcomes associated with infections secondary to carbapenem-resistant isolates among 99 patients when compared with a similar number of patients with infections caused by carbapenem-susceptible organisms. It was concluded that infections caused by KPC producers were associated with a longer duration of mechanical ventilation ($p = 0.04$), exposure to antimicrobials (cephalosporins, $p = 0.02$; carbapenems, $p < 0.001$), and higher mortality due to infection (38% vs 12%, $p < 0.001$) [16]. Measures such as chlorhexidine gluconate (CHG) bathing for skin antisepsis have also been studied in addition to standard precautions to prevent the spread of resistant gram-negative organisms. Chung and colleagues carried out an interrupted time series study to determine the effect of daily CHG bathing on carbapenem-resistant *Acinetobacter baumannii* acquisition in a medical ICU. A 12-month CHG bathing period was compared with a 14-month control period. A reduction of 51.8% was observed in CRAB acquisition rates following the introduction of CHG bathing (44.0 vs 21.2 cases/1000 at risk patient days, $p < 0.001$) [17].

In addition to the inpatient setting, CRE infections are an emerging threat in long-term acute-care hospitals (LTACHs) where patients are at high risk for acquisition and transmission of these organisms. Moreover, the residents of these facilities can also introduce CRE into hospitals during admissions. In a study conducted in four LTACHs, a stepped-wedge design was used to assess the effect of a bundled intervention (screening patients for KPC rectal colonization, contact isolation, daily CHG bathing for all patients and healthcare worker education, and compliance monitoring). A total of 3894 patients from the preintervention period were compared to 2951 patients admitted after the introduction of the intervention bundle. With this strategy, the incidence rate of KPC colonization demonstrated a significant decline in the intervention arm (4 vs 2 acquisitions per 100 patient-weeks; $p = 0.004$) [18].

Vancomycin-Resistant *Enterococcus*

VRE have been recognized as a cause of HAIs since the 1980s and are implicated in about 20,000 infections in the United States annually [19]. Guidelines for VRE prevention have been in place for over two decades. Recommendations include surveillance testing, contact precautions, hand hygiene, and limiting the use of vancomycin, without a consensus on the best approach [15]. A recent meta-analysis identified hand hygiene as a more effective strategy to prevent VRE infections when compared to contact precautions [20]. Of note, the small number of studies focusing primarily on VRE precluded meta-analysis for surveillance screening and environment decontamination.

Candida auris

C. auris is an emerging fungal pathogen. It is often resistant to multiple antifungal agents and is difficult to identify using standard laboratory methods. It can cause outbreaks in healthcare facilities. *C. auris* has been isolated from various body sites such as ear canals, wounds, the biliary tract, the respiratory tract, and urine. Bloodstream infections have constituted about 50% of the infections reported in the United States [21]. Asymptomatic patients may harbor *C. auris* on skin, nares, oropharynx, rectum, or other body sites. Healthcare facilities may consider AST to screen contacts of patients with *C. auris* infection or colonization and those with an overnight stay in a healthcare facility outside the United States over the past year if cases of *C. auris* had been reported in that country. Healthcare facilities with evidence or suspicion of ongoing transmission may perform point-prevalence surveys to estimate the burden of colonization and institute necessary measures including isolation and institution of contact precautions [22]. Guidelines for the optimal control and prevention of *C. auris* infections and asymptomatic carriage are currently evolving.

Severe Acute Respiratory Syndrome Coronavirus 2

Severe acute respiratory syndrome virus coronavirus 2 is a beta coronavirus, first identified in December 2019. The infection has been named coronavirus disease 2019 (COVID-19). The disease spectrum ranges from asymptomatic infection to severe pneumonia and acute respiratory distress syndrome (ARDS). The case fatality associated with COVID-19 is determined by factors such as age, sex, comorbid health conditions, race, and ethnicity, and values ranging from 0.1% to 25% have been reported in the literature [23]. This highly communicable disease evolved into a pandemic and overwhelmed the global healthcare infrastructure.

The recommendations to prevent transmission include implementation of hand hygiene, environmental cleaning, contact precautions using impermeable gowns and gloves, eye protection and droplet precautions for patients with mild infection and low supplemental oxygen requirements, and those not undergoing aerosol-generating procedures (AGPs such as intubation, noninvasive ventilation, bag ventilation, bronchoscopy, nasopharyngeal sampling, etc.). Airborne precautions are recommended for patients undergoing AGPs. Additional transmission mitigation strategies include tracing and testing contacts of patients with COVID-19, quarantining individuals with high-risk exposures to patients with COVID-19, universal masking, optimization of engineering controls, maintaining physical distancing of six feet between individuals, limiting visitors, and minimizing physical interaction with patients by introducing telemedicine. Healthcare facilities may consider pre-procedure and/or pre-admission COVID-19 testing to identify individuals with COVID-19 and take necessary steps to minimize the transmission of infection [24]. Infection prevention personnel should be promptly notified regarding the detection of SARS-CoV-2 PCR-positive patients and employees to ensure that necessary additional measures such as isolation and contact tracing may be deployed expeditiously.

Early in 2020, COVID-19 overwhelmed healthcare supply infrastructure globally and resulted in constrained resources and shortages of personal protective equipment (PPE), specifically N-95 masks. N-95 masks are designed for single use. However, many healthcare facilities adopted N-95 reuse or extended use guidelines and/or prioritized the use of N-95s for AGPs during periods of shortage. Limited reuse refers to using the same N-95 masks for multiple patient encounters, but removing the mask following each encounter to be stored or decontaminated. Ultraviolet germicidal irradiation, vaporous hydrogen peroxide, and moist heat are strategies that have been deployed for N-95 mask decontamination. Extended use means wearing an N-95 mask for multiple patient encounters without doffing the mask between patients. N-95 masks must be checked for a tight seal around the face and mouth upon each use. Masks with poor fit, damage, and visible soiling or contamination must be discarded [25].

Evidence for Horizontal Infection Control Strategies

This approach encompasses the implementation of measures such as hand hygiene, universal decolonization, universal masking, selective digestive tract decolonization (SDD), antimicrobial stewardship, and environmental decontamination to prevent infections and emergence of MDROs regardless of the colonization status of patients [7].

Hand Hygiene

Hand hygiene has been the cornerstone of infection prevention for over a century and is often considered the most important infection prevention strategy [26]. Transmission of healthcare-associated organisms through contamination of healthcare workers' (HCWs) hands has been well-studied and established as an area of major focus. To be transmissible, the organisms must be present on a patient's skin or have contaminated the environment, come in contact with and be transferred to hands of HCWs, and survive on their skin for several minutes, with failure to be eradicated due to inadequate hand hygiene and be spread to another patient as a result of direct skin contact. The adherence of HCWs to hand hygiene varies across centers and ranges from 5% to 89% [27]. Hand hygiene is effective at preventing spread of organisms such as MRSA, VRE, and resistant gram-negative organisms. The CDC currently recommends the following five moments for hand hygiene: before patient contact, before performing aseptic procedures, following exposure to body fluids, after contact with patients, and following contact with their surroundings [28]. Strict compliance with hand hygiene may reduce the rates of HAIs by up to 40% [29].

Universal Decolonization

While conventional methods, such as hand hygiene, have been in place for a long time, there has been a recent surge in the use of CHG for universal decolonization with its use being more widespread in ICUs. Multiple studies have been conducted to examine the effect of CHG bathing on the acquisition of MDROs and the incidence of HAIs. Several studies evaluating CHG bathing were published in 2013. Climo and colleagues carried out a multicenter cluster-randomized, non-blinded crossover trial to evaluate the effect of daily CHG bathing for 6 months compared to bathing with nonantimicrobial washcloths in nine intensive care units and bone marrow transplant units. A total of 7727 patients were included in the study. The results showed a significant reduction in overall bloodstream infections (4.78 cases per 1000 patient-days with CHG bathing vs 6.60 cases per 1000 patient-days with nonantimicrobial cloth; $p = 0.007$) as well as the acquisition of MDROs (5.10 cases per 1000 patient-days with CHG bathing vs 6.60 cases per 1000 patient-days with nonantimicrobial washcloths; $p = 0.03$) [30]. Huang and colleagues conducted a pragmatic cluster-randomized trial among 74,256 ICU patients randomized to three different strategies: screening and isolation for MRSA; targeted MRSA decolonization; and universal decolonization. The hazard ratios for bloodstream infection with any pathogen were 0.99, 0.78, and 0.56 among the three groups, respectively ($p < 0.001$), demonstrating a significant reduction in the universal decolonization group [31]. Similarly, a cluster-randomized crossover trial including 4947 pediatric ICU admissions investigated the impact of daily bathing either with CHG or standard practice on infection acquisition during two 6-month study periods. Per-protocol analysis demonstrated a lower incidence of bacteremia among the CHG bathing group when compared with standard practice (3.28 per 1000 days vs 4.93 per 1000 days; $p = 0.044$) [32]. While the results of these studies were promising, a recent pragmatic cluster-randomized crossover trial did not support daily CHG bathing. A total of 9340 patients admitted to five adult ICUs were included in the study and bathed daily with either CHG or nonantimicrobial cloths for 10 weeks, with a 2-week washout period prior to switching to the alternate bathing treatment for 10 weeks. Intervention with CHG bathing did not lead to a significant reduction in the incidence of HAIs [33]. It is important to note that the overall low rates of HAIs and single-center design of this study may have impacted its results.

With the heightened interest in the use of CHG as a disinfectant in the healthcare setting, emerging resistance has been a concern. CHG resistance is attributed to *qacA/B* genes among MRSA and *qacE* genes among *Klebsiella* species which encode multidrug efflux systems [34, 35]. CHG susceptibility testing is not routinely performed and no breakpoints have been established by the Clinical and Laboratory Standards Institute (CLSI) [35]. In the pediatric study conducted by Fritz and colleagues mentioned above, 10/10891 (0.9%) patients harbored CHG-resistant *S. aureus* at baseline and two of these underwent daily CHG bathing for 5 days. At 1 month, there was no difference in colonization status among these patients when compared to patients carrying no CHG-resistant microorganisms ($p = 1.0$) [13]. The lack of an appreciable association may, however, be attributed to the low overall prevalence of CHG resistance in the study. Continued vigilance for emerging CHG resistance seems warranted.

Universal Masking

Universal masking refers to implementation of mask-wearing for all individuals. The rationale for doing so is that masks contain respiratory secretions and prevent transmission of infectious respiratory particles to others and act as a physical barrier to secretions from those who may not be wearing masks. This strategy was widely implemented in healthcare facilities to curb the spread of COVID-19. In a study by Tong et al., universal masking resulted in a decline in the incidence of respiratory viral infections in a neonatal step-down unit for very low birth weight infants from 1.1 to 0.3 per 1000 patient-days ($p = 0.008$) [36]. However, universal masking is not a panacea and must be combined with other strategies such as hand hygiene, environmental cleaning, and be used with other PPE including gowns, gloves, and eye protection where indicated.

Selective Digestive Tract Decolonization

SDD is a prophylactic measure to reduce infections caused by *Candida*, *Staphylococcus aureus,* and gram-negative organisms among patients with gastrointestinal carriage of these organisms. Protocols vary across centers, and can include the following: a short course of parenteral antibiotics such as a third- or fourth-generation cephalosporin, non-absorbable enteral agents (e.g., polymixin E, amphotericin B, and vancomycin), and oral and rectal surveillance cultures on admission and at 2 week intervals thereafter to monitor the effectiveness of SDD. Although multiple trials have demonstrated its effectiveness in reducing pneumonias and bloodstream infections among critically ill patients, its use remains controversial due to concerns such as the selection of resistant organisms [37]. Reig and colleagues conducted a retrospective observational study to evaluate the efficacy of intestinal decolonization among 45 patients with a history of at least two ESBL *E. coli* infections and persistent intestinal carriage (determined by positive rectal and/or stool cultures). Patients were treated with either low- or high-dose oral colistin or oral rifaximin for 4 weeks. ESBL *E. coli* eradication occurred in 19/45 (42%) patients. The use of single-drug oral regimens for intestinal decolonization is not well-established and additional studies are required to further explore this [38].

Antimicrobial Stewardship

Antimicrobial Stewardship Programs (ASPs) are considered crucial for combatting the emergence of antimicrobial resistance and can be linked with infection prevention programs. According to the CDC, 20–50% of all antibiotics used in the United States are unnecessary. Antibiotic use is associated with drug reactions, *Clostridioides difficile* infections as well as antibiotic resistance [39]. A bundle approach consisting of staff education, early identification, expanded infection control measures including hand hygiene, and judicious use of antibiotics was introduced at a tertiary care center in the United States to manage high *C. difficile* infection rates (7.2 per 1000 hospital discharges). The rate of *C. difficile* infections fell to 3.0 per 1000 hospital discharges within 6 years (71% reduction, $p < 0.001$) [40].

Environmental Cleaning

Contaminated surfaces such as bedrails, bed surfaces, nurse call buttons, television remotes, and medical equipment have been identified as reservoirs for organisms such as MRSA, VRE, *C difficile*, *Acinetobacter* species, *Pseudomonas aeruginosa*, SARS-CoV-2, and norovirus. Persistence of these organisms in the environment and ineffective environmental cleaning strategies result in transmission of these organisms to other patients [41]. The current CDC recommendations for effective environmental decontamination include assignment of dedicated staff members to clean different units, thorough decontamination of surfaces such as bedrails, charts, and doorknobs along with frequent monitoring of units to assess for adherence to outlined protocols [15].

Financial Considerations

According to a decision tree analysis to compare costs of various MRSA surveillance strategies, universal MRSA screening was deemed more cost-intensive compared to targeted surveillance, but interestingly, the latter was more cost-effective than no screening [42]. However, when MRSA surveillance strategies with and without decolonization were compared to other approaches such as universal contact precautions and universal decolonization in a recent cost-effectiveness model using a hypothetical cohort of 10,000 adult ICU patients, universal decolonization was deemed the most cost-effective infection prevention strategy for MRSA colonization prevalence of up to 12%; as this drops from 12% to 5%, AST with selective decolonization may be the more optimal approach, emphasizing the consideration of local factors prior to making decisions regarding the best infection prevention strategy [43]. According to an estimate focusing mainly on infection prevention in the ICU setting and surgical units, interventions such as hand hygiene, contact isolation in the setting of known MDRO infections or colonization, and environmental cleaning led to a net global saving of US $13,179 per month between 2009 to 2014 by reducing HAIs such as central line-associated bloodstream infections, ventilator-associated pneumonias, and surgical site infections [44].

Conclusion

MDROs are a major healthcare concern and along with HAIs have become a major infection prevention focus. Vertical and horizontal infection control strategies have been used to combat HAIs. These strategies include measures such as active surveillance testing, hand hygiene programs, universal masking, universal skin decolonization with antiseptics such as CHG, and antimicrobial stewardship. Many studies have shown beneficial results with lower rates of HAIs resulting from both vertical and horizontal strategies. However, there is still controversy over which strategies are most optimal in different settings. In terms of HAI prevention, generally horizontal strategies are more likely to have a broader impact and are more cost-effective. While a horizontal approach seems optimal for many situations, adverse effects of horizontal strategies must also be considered. For instance, a theoretical concern is the development of CHG resistance with the wide deployment of CHG bathing. Although vertical strategies have a role in the management of outbreaks of specific pathogens, in general horizontal strategies have a greater impact at a lower cost.

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