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Infection Control through Environmental Hygiene: Challenges and Solutions

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Abstract

The healthcare environment plays a critical role in the transmission of significant healthcare-associated pathogens, including vancomycin-resistant enterococci (VRE), Clostridium difficile, Acinetobacter spp., methicillin-resistant Staphylococcus aureus (MRSA), and norovirus. These pathogens can persist on surfaces for extended periods, increasing the risk of acquisition by patients and healthcare workers. Historically, hospital cleanliness was primarily an aesthetic priority, but growing evidence has demonstrated the benefits of enhanced cleaning and decontamination in controlling outbreaks and reducing sporadic transmission. Effective cleaning has been shown to decrease environmental contamination and patient acquisition rates for various pathogens, including MRSA, VRE, C. difficile, and Acinetobacter spp. However, the optimal cleaning methods, frequency, equipment, and standards for surface cleanliness remain subject to ongoing debate. Manual cleaning using detergents or disinfectants is the most common approach, with a focus on high-touch surfaces and frequently used equipment. Automated decontamination devices, such as those utilizing steam, UV light, ozone, or hydrogen peroxide vapor, have emerged as promising adjuncts to manual cleaning, particularly for terminal disinfection. However, their cost-effectiveness and impact on healthcare-associated infection rates require further evaluation. Antimicrobial surfaces and innovative technologies offer additional strategies for enhancing environmental hygiene. Nonetheless, cleaning remains a fundamental infection control measure in modern hospitals, and further research is needed to optimize its implementation in a practical and economically feasible manner.

Keywords: Infection control, Environmental hygiene, Healthcare-associated infections (HAIs), Pathogen transmission, Disinfection strategies, Surface decontamination

Introduction

The risk of infection from contaminated healthcare surfaces has been widely debated. It is now well-established that the healthcare environment can facilitate the transmission of significant healthcare-associated pathogens, including vancomycin-resistant enterococci (VRE), Clostridium difficile, Acinetobacter spp., methicillin-resistant Staphylococcus aureus (MRSA), and norovirus. These pathogens are frequently shed by patients and staff, contaminating surfaces where they can persist for days and increase the risk of acquisition by others. Environmental screening has consistently identified contamination of equipment, items, and general surfaces within patient bed spaces and rooms, often extending across multiple clinical areas within healthcare facilities. Healthcare workers' hands are frequently exposed to these contaminated surfaces during patient care, thereby facilitating the onward transmission of pathogens. Furthermore, unrecognized environmental reservoirs may serve as focal points for outbreaks or continued sporadic transmission. Recent studies have indicated that the risk of acquiring VRE, MRSA, Acinetobacter spp., Pseudomonas spp., or C. difficile increases when new patients are admitted to rooms previously occupied by colonized or infected patients. This supports the hypothesis that the healthcare environment plays a critical role in pathogen transmission. The survival characteristics of specific species or strains on surfaces may influence infection risk in inadequately cleaned rooms or patient spaces.

Historically, maintaining hospital cleanliness was primarily considered an aesthetic priority, which helped justify the resources devoted to it, despite limited evidence linking cleanliness directly to infection risk (Nightingale, 2022). During the 1990s in the United Kingdom, cost-saving measures targeted cleaning services, leading to significant reductions in housekeeping staff and cleaning hours in the absence of compelling scientific evidence. Basic cleaning was not viewed as crucial for infection control, providing a rationale for budget cuts. However, the late 1990s and early 2000s saw a significant increase in hospital-acquired MRSA infections in the United Kingdom, prompting renewed attention to pathogen transmission, survival in the environment, and potential environmental reservoirs. Cleaning practices became a central focus for patients and policymakers, supported by a growing body of evidence demonstrating the benefits of enhanced cleaning and decontamination during routine operations and costly outbreak responses. In response, national agencies and local health boards revised housekeeping policies to emphasize the importance of basic hospital hygiene, implement formal monitoring systems, provide feedback to cleaning staff, and conduct surveillance of key environmental pathogens. Despite this progress, controversies remain regarding the role of cleaning in controlling hospital-acquired infections (HAIs) relative to other measures, such as patient screening, isolation, hand hygiene, and antimicrobial stewardship. The current evidence base is frequently criticized for its limited quantity and quality (Mitchell et al., 2013; Popp, 2013).

Globally, the cleaning process itself is subject to ongoing debate concerning the frequency, methods, equipment, benchmarks, monitoring, and standards for surface cleanliness. Cleaning policies vary significantly, even within the same healthcare district, depending on available resources and political support. While affluent nations debate the routine use of advanced, non-touch cleaning technologies, resource-poor settings face challenges in providing basic equipment, clean water, and adequate staffing. Furthermore, scientific and clinical debates persist over the effectiveness of detergent-based cleaning approaches, commonly used in the United Kingdom and northern Europe, compared to disinfectant-based methods, favored in the United States and Australia. In some countries, governmental targets for HAI rates have helped prioritize infection control, including environmental cleaning practices. For instance, in the United States, hospitals reporting preventable HAIs and poor hygiene may face financial penalties. However, assessments of environmental hygiene often rely on patient perceptions of cleanliness rather than scientific measurements. These incentives, penalties, and public reporting requirements undoubtedly influence hospital operations and outcomes under mandatory inspections (Greaves et al., 2012).

Additional challenges pertain to the cleaning workforce, as many staff receive minimal training and face limited career advancement opportunities compared to other professions. Housekeeping roles are often characterized by low pay, poor working conditions, and high physical demands. Cleaning personnel frequently face risks of injury, chemical exposure, and infection from cleaning facilities housing patients with transmissible pathogens.

This review evaluates the existing evidence supporting basic cleaning as a critical intervention to protect patients from HAIs. It explores both manual and automated cleaning methods, discusses the ongoing disinfectant debate, examines the potential of antimicrobial surfaces, and underscores the need for surface cleanliness standards and routine monitoring. While much of the evidence originates from affluent countries, the United Kingdom's cleaning policies are used as illustrative examples. Cleaning remains a fundamental infection control measure in 21st-century hospitals, but further research is required to optimize its delivery in a timely and cost-effective manner.

Cleaning and HAI

Although evidence supporting routine cleaning remains limited, it is almost universally included as part of outbreak response measures in cases without an identifiable common source. Numerous reports highlight cleaning as a critical control component during outbreaks involving norovirus, VRE, C. difficile, MRSA, and multidrug-resistant (MDR) Gram-negative bacilli, including Acinetobacter spp. (Donskey, 2013). These pathogens thrive in hospital environments, contaminating surfaces, equipment, and even the air. While much of the evidence linking cleaning to HAI prevention is derived from outbreak investigations, some studies have examined the impact of enhanced or alternative cleaning practices on environmental contamination in routine settings. Several of these studies have used standards such as ATP bioluminescence or microbiological screening to evaluate cleaning effectiveness and have modeled these findings against patient HAI outcomes (Salgado et al., 2013).

MRSA

Evidence supporting the role of near-patient surfaces in hospitals as reservoirs for methicillin-resistant Staphylococcus aureus (MRSA) was first presented by Boyce et al. in 1997. This study demonstrated that healthcare workers could contaminate their gloves by touching surfaces near patients colonized with MRSA. However, this finding contrasts with a study published 16 years later, which revealed that even thorough cleaning failed to reduce healthcare workers' gown and glove contamination after caring for patients with MRSA or multidrug-resistant Acinetobacter spp. While the risk of healthcare worker contamination with MRSA remains inconclusive, research has shown that basic cleaning can effectively eliminate MRSA from hospital environments, benefiting patients. For instance, over a 14-month period, 13 patients acquired MRSA in a dermatology ward despite standard infection control measures. Environmental sampling identified MRSA in communal showers and on a blood pressure cuff, with DNA typing confirming identical patterns in patient and environmental isolates. Enhanced cleaning of shared areas and replacing the blood pressure cuff between patients resulted in a decrease in MRSA cases. In another instance, a year-long MRSA outbreak in a urology ward persisted despite comprehensive infection control measures such as patient isolation and hand hygiene protocols. After identifying the outbreak strain on general ward surfaces, cleaning hours were doubled from 60 to 120 hours per week, leading to a marked reduction in new MRSA cases. This intervention was estimated to save at least £28,000 (approximately $45,000).

In an intensive care unit (ICU) setting, an outbreak of vancomycin-intermediate resistant MRSA presented challenges for infection control staff. The outbreak was only controlled after the implementation of enhanced cleaning measures, among other interventions. However, due to the simultaneous application of multiple measures, the specific impact of cleaning interventions or barrier precautions could not be precisely determined. Beyond outbreak situations, a prospective controlled crossover trial assessed the effect of targeted cleaning under routine conditions in two acute-care surgical wards. During two consecutive six-month periods, an additional cleaner prioritized high-touch surfaces and clinical equipment for detergent-based cleaning from Monday to Friday. When routine cleaning resumed without additional focus on high-risk areas, nine patients developed acute MRSA infections, one of whom died, and another required surgical intervention. By contrast, during the enhanced cleaning periods, only four patients acquired MRSA infections. Statistical analysis, accounting for weekly MRSA colonization pressures, predicted 13 new cases during the enhanced cleaning periods but observed only four, demonstrating that targeted cleaning of high-touch areas with detergent wipes reduced postoperative MRSA infections and saved an estimated £30,000 ($51,000) annually.

A separate study evaluated a new cleaning protocol in 10 ICUs for rooms previously occupied by patients colonized with MRSA or VRE. The protocol included using a bucket method for soaking cleaning cloths and providing feedback to cleaning staff with fluorescent markers. Although quasi-experimental, the study revealed reduced environmental contamination by MRSA and VRE after cleaning, with contamination rates dropping from 45% to 27%. Concurrently, MRSA acquisition among patients decreased by 49%, and VRE acquisition fell by 29% ($P < 0.001$ for both).

Two recent studies explored the impact of control bundles that included environmental decontamination, patient screening, and other measures on MRSA rates. The first study, conducted in three American hospitals with a combined 777 beds, employed a pulsed xenon UV (PX-UV) device along with a 5-day topical clearance protocol for colonized patients. This approach led to a 56% reduction in hospital-acquired MRSA rates across the healthcare system over six months ($P = 0.001$) (Simmons et al., 2013).

The second study, conducted in a 300-bed Australian hospital, assessed the use of hydrogen peroxide (HP) decontamination in comparison to detergent cleaning over six years (Mitchell et al., 2014). A retrospective before-and-after design evaluated the environmental and patient outcomes of the two cleaning methods. Environmental screening revealed MRSA contamination in 25% of rooms following detergent cleaning compared to 19% after HP decontamination ($P < 0.001$). While the proportion of rooms with persistent MRSA contamination decreased by 3.5% with HP decontamination, the reduction was not statistically significant ($P = 0.08$). Over six years, MRSA acquisition rates fell from 9.0 to 5.3 per 10,000 patient-days during the transition from detergent cleaning to HP decontamination ($P < 0.001$).

Both studies concluded that enhanced decontamination methods contributed to reduced MRSA rates; however, further research is needed to isolate the specific effects of PX-UV and hydrogen peroxide decontamination. As with earlier studies, the relative impact of additional measures such as patient screening and the use of decontamination technologies could not be clearly delineated.

VRE

Vancomycin-resistant enterococci (VRE) are recognized for their capacity to persist in hospital environments over extended periods. Various cleaning protocols have been shown to be insufficient in eradicating VRE from numerous surfaces, even with the use of potent disinfectants. Reports highlight that contamination persists when cleaning cloths are reused on multiple surfaces, when disinfectants are applied with insufficient contact time, or when surfaces are sprayed and wiped rather than actively scrubbed. This resilience is not exclusive to VRE, as other pathogens also survive cleaning processes. However, VRE appears particularly resistant, enduring even double bleach-based cleaning regimens.

Disinfectant protocols can be effective against VRE when near-patient surfaces, such as bed rails, and frequently touched surfaces, like door handles, are scrubbed daily. Evidence suggests that rigorous cleaning can mitigate VRE. A pivotal study in 2006 evaluated the effect of improved cleaning on VRE transmission in a medical ICU, first as a standalone intervention and subsequently combined with a hand hygiene program. Enhancing cleaning efficiency reduced both surface contamination and patient acquisition of VRE, and introducing the hand hygiene initiative further lowered these rates to their lowest observed levels. Additionally, contamination on healthcare workers' hands decreased significantly.

Rising VRE cases in a Brazilian hospital prompted the adoption of various measures, including enhanced environmental cleaning, contact precautions, and an educational program. Cleaning improvements incorporated the use of bleach for bathroom surfaces and 70% alcohol for furniture and patient equipment. This comprehensive approach successfully curtailed the spread of VRE hospital-wide, including in intensive care units, reducing acquisition rates from 1.49 to 0.33 ($P < 0.001$) (Rossini et al., 2012). Similarly, bleach-based terminal cleaning was a component of an earlier intervention package used to control VRE in a hemato-oncology unit. In South Korea, a "bundle" of interventions aimed at containing a VRE outbreak in three ICUs included intensive cleaning and surface screening cultures. Among the 50 patients identified with VRE, the majority ($n = 46$) were colonized with Enterococcus faecium (VREF). During the first two months of the outbreak, PFGE analysis of VREF isolates identified six main strain types, with clusters linked to two strains. Housekeeping staff used 5% sodium hypochlorite to clean surfaces three times daily. After five months of implementing this package, the weekly prevalence rate of VRE dropped from 9.1/100 to 0.6/100 patient-days.

Another study introduced a multicomponent intervention package centered on bleach-based cleaning in response to increasing VRE cases. Additional cleaning supervisors oversaw a standardized cleaning regimen using a detergent and sodium hypochlorite product (1,000 ppm). Other measures included alcohol-based hand hygiene, the replacement of long-sleeved gowns with sleeveless aprons, and the use of gloves. Comparisons before and after the intervention revealed a 24.8% reduction in new VRE colonization ($P = 0.001$) and a 66.4% reduction in environmental contamination ($P = 0.012$), despite a consistent proportion of patients colonized on admission. Additionally, VRE bacteremia decreased by over 80% ($P < 0.001$), while vancomycin-susceptible enterococcal bacteremia rates remained unchanged ($P = 0.54$). These findings suggest that resistant enterococci are more likely to be acquired from environmental reservoirs, whereas susceptible enterococci may originate from patients' endogenous flora. The "bleach-clean" intervention significantly reduced new VRE acquisitions and VRE bacteremia rates, particularly among vulnerable patients.

The robust environmental persistence of VRE underscores the increased risk of acquisition for patients placed in rooms previously occupied by individuals colonized or infected with VRE. The clinical and environmental efficacy of hydrogen peroxide vapor (HPV) disinfection was evaluated for rooms previously occupied by patients with MRSA, Clostridioides difficile, multidrug-resistant Gram-negative bacilli, and VRE. While HPV decontamination did not significantly reduce the risk of acquiring MRSA, C. difficile, or multidrug-resistant Gram-negative bacilli, patients admitted to HPV-treated rooms were 80% less likely to acquire VRE. These findings suggest that eliminating persistent environmental reservoirs of VRE may be critical for reducing acquisition risk, emphasizing the importance of prioritizing cleaning and disinfection for VRE control, potentially more so than for other hospital pathogens (Passaretti et al., 2013).

C. difficile

The effectiveness of cleaning practices in controlling Clostridioides difficile (C. difficile) is well-established. Chlorine-releasing disinfectants have been shown to reduce environmental spore loads in rooms contaminated with C. difficile, with evidence suggesting that this contributes to decreased recurrence and transmission of C. difficile-associated infections (CDI). Products with higher concentrations of chlorine, such as those releasing 5,000 mg/liter of free chlorine, have demonstrated particular efficacy. These chlorinated products are especially beneficial in units with elevated CDI rates, such as elderly care or stroke rehabilitation wards, or during outbreaks. However, the overall efficacy of disinfectants in reducing spores and CDI rates depends on several factors, including the training and knowledge of cleaning staff, the contact time of disinfectants on surfaces, and the time allocated for cleaning tasks. Additionally, certain strains of C. difficile may possess intrinsic or acquired traits that enhance resistance to disinfection.

A 2007 study assessed the impact of enhanced bleach cleaning in two intensive care units (ICUs) following an increase in CDI cases. One ICU implemented comprehensive bleach cleaning throughout all areas, including staff-only spaces, with clinical equipment cleaned twice daily using hypochlorite-containing cloths. The second ICU adopted enhanced bleach cleaning specifically in isolation rooms occupied by patients with CDI. Both units observed reductions in CDI rates in subsequent months, with the decreased rates sustained for at least two years following the cleaning intervention.

Elevated CDI rates in three American hospitals prompted a switch in terminal room cleaning practices, replacing a quaternary ammonium disinfectant with dilute bleach. This involved wiping all room surfaces, from ceiling to floor, with bleach-soaked towels after patient discharge. The prevalence density of C. difficile decreased by 48%, with a sustained reduction in hospital-acquired CDI rates. Another group utilized 0.55% bleach wipes for daily cleaning in two medical units with high CDI incidence rates. Prior to the intervention, 31 patients acquired C. difficile on these wards, compared to just four cases afterward, representing a seven-fold reduction. No other infection control measures were introduced during this period apart from the targeted bleach wipe cleaning.

A systematic cleaning and disinfection program evaluated the presence of C. difficile on frequently touched surfaces in CDI rooms following cleaning. Over 21 months, three sequential interventions were introduced: (i) fluorescent markers at key sites for monitoring and feedback to cleaners, (ii) automated UV equipment for enhanced disinfection, and (iii) support from a dedicated team responsible for daily assessment of terminally cleaned CDI rooms. The use of fluorescent markers improved cleaning quality at frequently touched sites from 47% to 81% ($P < 0.0001$). The proportion of sites testing positive for C. difficile decreased by 14% ($P = 0.024$), 48% ($P < 0.001$), and 89% ($P = 0.006$) for interventions 1, 2, and 3, respectively, compared to baseline. Before the study, positive C. difficile cultures were found in two-thirds of CDI rooms after disinfection, but these rates fell by 57%, 35%, and 7% during interventions 1, 2, and 3, respectively.

Additional evidence supporting the role of cleaning and disinfection in reducing CDI comes from an English study. Researchers applied a statistical breakpoint model to incidence rates of likely hospital-acquired CDI at a university hospital (2002–2009) and a district general hospital (2005–2009). Infection control interventions were categorized into antibiotics, cleaning, isolation, and other measures, and mapped against statistical breakpoints. The breakpoints aligned with the introduction of novel cleaning practices rather than other interventions. Statistical modeling demonstrated that enhanced cleaning activities were most likely responsible for incremental reductions in CDI rates at both hospitals (Hughes et al., 2013).

While cleaning and decontamination strategies are critical for reducing patient acquisition rates, antimicrobial policies also play a key role in controlling C. difficile. Strict restrictions on first-line use of cephalosporins and quinolones in a district general hospital led to a 77% reduction in nosocomial C. difficile acquisition, from 2.398 to 0.549 cases per 1,000 patient beds. This reduction occurred without additional infection control measures, highlighting the importance of antibiotic stewardship in CDI control (Dancer et al., 2013). Spatiotemporal modeling has further demonstrated that protecting patients from C. difficile acquisition through prudent antibiotic selection is more effective than attempting to control transmission after symptom onset. However, in cases where sepsis necessitates the use of broad-spectrum antibiotics, stringent environmental cleaning remains essential to prevent further transmission.

Acinetobacter

Numerous studies have highlighted the critical role of cleaning in controlling outbreaks of Acinetobacter species, particularly those caused by multidrug-resistant strains in critical care environments. One investigation documented an outbreak of multidrug-resistant A. baumannii involving over 30 patients across two intensive care units (ICUs). Epidemic strains were detected in environmental reservoirs throughout both ICUs, necessitating their complete closure for terminal disinfection to control the outbreak. Another study described a prolonged outbreak in a neurosurgical ICU, which led to continuous environmental sampling to identify persistent reservoirs. The epidemic strain was frequently found on hand-touch surfaces near patients, and a clear link was established between the level of surface contamination and the acquisition of new patient cases. The authors emphasized that comprehensive cleaning is essential for controlling Acinetobacter outbreaks in ICU settings; however, optimal routine cleaning practices remain undefined.

In another study, the spread of a multidrug-resistant A. baumannii strain in a critical care unit was investigated, providing environmental sampling data during an outbreak affecting over 60 patients. A correlation was observed between the number of positive environmental cultures and the incidence of new patient cases. Systematic environmental screening enabled targeted cleaning efforts, which helped bring the outbreak under control (Delgado Naranjo et al., 2013).

An investigation into a pediatric burn ward outbreak involving Acinetobacter revealed that frequently handled clinical equipment served as an outbreak reservoir. The outbreak occurred after the introduction of computers beside every child's bed. Environmental screening identified the organism on various surfaces in the patient rooms, including the plastic covers of computer keyboards. At the time, there were no recommendations for cleaning bedside computers and their components. Targeted infection control measures, including decontamination of the plastic covers and mandatory glove use by staff before handling the computers, were implemented, successfully ending the outbreak.

A 3-year prospective study conducted in intensive and coronary care units assessed a bundle of interventions aimed at reducing the long-term prevalence of drug-resistant Acinetobacter. These interventions included a hand hygiene program, patient surveillance, barrier precautions, contact isolation, patient cohorting, and intensive cleaning using sodium hypochlorite (1:100). Prior to the interventions, the rate of A. baumannii colonization and/or infection was 3.6 cases per 1,000 patient-days, which decreased by 66% to 1.2 cases per 1,000 patient-days ($P < 0.001$) within the first year. By the second year, the rate further declined by 76% to 0.85 cases per 1,000 patient-days ($P < 0.001$).

Another ICU outbreak affecting 18 patients was traced to a sink in one of the patient rooms. The sink trap was identified as the reservoir, suggesting potential contamination throughout the horizontal drainage system. Implementation of a bleaching protocol eliminated the reservoir and halted further acquisition of multidrug-resistant (MDR) A. baumannii. However, additional infection control measures, such as contact isolation for affected patients, hand hygiene training, nurse education, the use of alcohol-based hand gel, and direct cleaning observation, were also introduced. Thus, it was challenging to isolate the specific impact of reservoir decontamination amidst the multiple interventions implemented simultaneously.

Another study supported the importance of cleaning in managing Acinetobacter outbreaks. This outbreak occurred in an ICU and involved an extremely resistant strain of A. baumannii resistant to carbapenem antibiotics. During the outbreak, carbapenem-resistant A. baumannii was isolated from multiple environmental samples, including a mattress, vital signs monitor, near-patient horizontal surfaces, computer components, and a glucometer. After unsuccessful cleaning with detergents and alcohol wipes, a commercial oxidizing disinfectant (Virkon S [50% potassium peroxomonosulfate, 15% sodium alkyl benzene sulfonate, and 5% sulfamic acid]) was introduced. The use of this disinfectant was associated with a rapid resolution of the outbreak. Although the authors noted the temporal association, they cautioned that outbreaks can sometimes resolve independently. They did not audit cleaning effectiveness, hand hygiene compliance, antimicrobial usage, or other potentially confounding factors. Nonetheless, the substantial and sustained decrease in cases following the use of the disinfectant was noteworthy.

Despite stringent manual cleaning and disinfection, complete elimination of Acinetobacter from the environment is not always achieved. This may be due to factors such as inadequate cleaning practices, overlooked high-risk sites, overwhelming bioburden, and either tolerance to or improper use of disinfectants. One study revealed that surfaces in rooms occupied by patients colonized with A. baumannii remained contaminated despite disinfectant-based cleaning. This study also noted contamination in rooms housing patients without recent A. baumannii cultures, suggesting the organism's long-term persistence in the patient environment. While a significant reduction in contamination was observed following disinfection, over half of the initially contaminated rooms still harbored the organism on various surfaces post-cleaning (Strassle et al., 2012).

Multidrug-Resistant Gram-Negative Bacilli

The role of cleaning in managing Acinetobacter outbreaks is widely acknowledged; however, the same cannot be definitively stated for outbreaks caused by multidrug-resistant (MDR) Gram-negative bacilli. Enhanced cleaning typically forms part of a broader set of activities implemented in response to cross-infection incidents during outbreaks. Numerous reports, however, document associations between coliforms and specific equipment, environmental reservoirs, or particular practices or products identified during outbreak investigations. In most cases, locating and eradicating a single reservoir successfully resolves the outbreak, often prompting publication due to the favorable outcome. Addressing outbreaks arising from single-source contamination is notably more straightforward than implementing extensive cleaning protocols that encompass diverse items and surfaces.

Outside outbreak contexts, it has traditionally been assumed that Gram-negative bacteria have limited survival on surfaces, leading to minimal investigation of their environmental role in healthcare-associated infections (HAIs). However, recent research challenges this notion, with increasing consensus that environmental cleanliness may be as critical for MDR coliforms as it is for MRSA and other pathogens (Tacconelli et al., 2014). Studies have shown that Escherichia coli and Klebsiella species can survive desiccation for over a year, while Serratia marcescens can persist for several months. Additional studies report the persistence of MDR coliforms across various healthcare environments, with evidence indicating that MDR Klebsiella is more frequently recovered from surfaces than MDR E. coli. One study screened the immediate surroundings of patients identified with carbapenem-resistant Enterobacteriaceae (CRE), finding contamination at approximately 25% of tested sites, likely originating from the patients themselves. This study also demonstrated that both sampling timing and local cleaning strategies influenced data on environmental contamination by CRE, a finding that likely applies to other pathogens as well (Lerner et al., 2013).

Beyond cleaning and sampling practices, the limited recovery of viable MDR coliforms and their associated infection risk from hospital surfaces may also be attributed to insensitive detection methods. Using a targeted sampling strategy, researchers investigated frequently touched surfaces near patients colonized by MDR coliforms (e.g., light switches, bed rails, bedside lockers, and mattress covers) and in shared bathrooms (e.g., shower handrails and sink faucets). Environmental sampling near one patient recovered MDR Klebsiella pneumoniae from four of six tested sites, all genetically indistinguishable from the strain found in the patient's urine. These contaminated sites included those close to the patient and within a communal bathroom. Despite relatively low recovery rates and short survival times (1.5 to 2 hours), the isolation of MDR coliforms from these surfaces suggests a high initial burden, with contamination likely occurring shortly before sampling.

Hospital sinks are among the most frequently implicated reservoirs for MDR Gram-negative bacilli, including MDR coliforms. Klebsiella pneumoniae strains with prolonged survival in plumbing components are often associated with extended-spectrum β-lactamase production. Persistent reservoirs of resistant K. pneumoniae have been identified at multiple sites associated with contaminated sinks in a large Scottish hospital. Similarly, four patients in a neurosurgical ICU acquired MDR K. pneumoniae, traced to another contaminated sink over a 7-month period. Replacing the sink and its associated pipes, alongside improved sink usage and decontamination practices, resolved the outbreak. Another protracted outbreak involving IMP-8-producing Klebsiella oxytoca in a Spanish ICU was only resolved after the removal of sinks, drain traps, and even the horizontal drainage system linking the sinks. When standard control measures fail to curtail an outbreak, alternative reservoirs should be investigated, especially if initial environmental screening does not identify the source (Vergara-López et al., 2013).

One outbreak of MDR Klebsiella was associated with improper disposal of patient fluids into nearby sinks instead of designated sluice areas (Lowe et al., 2012). A recent ICU audit reported that lower sink contamination rates were significantly linked to daily bleach disinfection and restricting sinks to handwashing rather than routine disposal of patient fluids.

Another outbreak of resistant K. pneumoniae demonstrated the risks associated with reusing disposable equipment. This outbreak primarily affected neonates, most of whom became infected shortly after birth or early during hospitalization. Cases were concentrated among neonates requiring mucous aspiration due to respiratory distress. Although individual aspiration tubes were used for each baby, they were rinsed in the same bowl of tap water between uses for the same baby. This bowl was not routinely cleaned, and the water remained unchanged between procedures. Unsurprisingly, the water was found to harbor the same resistant K. pneumoniae strain.

Evidence of the effectiveness of general surface cleaning alone in managing MDR Gram-negative organisms, even during outbreaks, remains limited. One report described additional cleaning following the recovery of carbapenemase-producing K. pneumoniae from patients in a UK hospital. Chlorine-based cleaning was implemented throughout the ward, including patient-associated items. However, this cleaning formed part of a broader infection control strategy that included a urinary catheter care bundle, patient record tagging, improved hand hygiene, and contact precautions. Another report detailed an educational initiative aimed at improving environmental cleaning and hand hygiene in an 11-bed gastrointestinal surgical ICU. While the high proportion of colonized patients suggested an underlying outbreak at the start, the introduction of terminal cleaning with glutaraldehyde, single-use equipment, barrier precautions, and improved hand hygiene reduced colonization rates from 70% to 40%, an outcome attributed to the combined intervention package.

Manual Cleaning: Process And Equipment

1. Routine Cleaning Practices

In hospital settings, environmental surfaces are regularly cleaned or cleaned and disinfected in accordance with predetermined cleaning protocols. These protocols may dictate cleaning frequency—such as hourly, daily, or biweekly—or be triggered by visible soiling, spillages, or patient discharge. The type and frequency of routine cleaning depend on factors like clinical risk, patient turnover, the volume of foot traffic, and the characteristics of the surfaces being cleaned. High-priority cleaning practices are implemented in critical areas such as operating theaters, intensive care units, transplant wards, and "clean" rooms where sterile medications are prepared. Other areas, including hospital kitchens, cafeterias, laboratories, and staff on-call rooms, also require targeted cleaning routines. Conversely, corridors, stairwells, offices, waiting rooms, and general-purpose areas are subject to less rigorous cleaning protocols.

Hospitals must provide a documented specification of cleaning services for all areas, whether delivered by in-house staff or external contractors. These specifications should undergo regular review by cleaning supervisors, hospital administrators, facility managers, and infection control teams. There is also an increasing emphasis on innovation and research in infection control, encouraging hospitals to test new cleaning technologies and disseminate their findings.

In the United Kingdom, routine cleaning primarily involves manual methods using basic equipment such as buckets, mops, brushes, brooms, wipes, and cloths. Additional equipment includes vacuum cleaners, floor polishers, and scrubbing machines. Hospital surfaces are categorized as either critical or noncritical. Noncritical surfaces include floors, furniture, soft furnishings (e.g., curtains), walls, ventilation grilles, and cupboards. Critical surfaces, by contrast, encompass frequently touched items such as handles, switches, keyboards, and noninvasive clinical equipment like stethoscopes and intravenous drip stands.

2. Noncritical Surfaces

Neutral detergents are used to remove soil from noncritical surfaces, employing either disposable or reusable cleaning materials. Detergent-based cleaning alone can remove over 80% of the bacterial load on hospital floors. However, mop water often becomes progressively contaminated, especially if reused without frequent changes or if cleaning is delayed by more than 24 hours. Such contaminated water can facilitate the spread of microbes and must be replaced with fresh detergent solutions every 15 minutes or between cleaning of bed spaces, whichever is sooner. Although disinfectants are sometimes employed for cleaning floors in high-risk areas, their ability to achieve lasting microbial reductions is not significantly greater than that of detergents.

Mop heads may be disposable or reusable, with usage guidelines specifying their duration or area of application. Reusable mop heads must be decontaminated daily to prevent microbial survival and subsequent contamination of cleaned surfaces, a risk that persists despite the use of disinfectants due to microbial resistance or biofilm protection (Vickery et al., 2012). Disposable wipes and cloths offer a convenient alternative, eliminating the need for decontamination; however, cleaning staff require adequate training to ensure proper use and disposal of these materials. In general, a single wipe or cloth should be used per room or bed space, excluding bathrooms, where separate cleaning materials are mandatory. Despite their convenience, disposable wipes can leave residues or moisture that attract soil and spoil surface appearance. Moreover, they can be costly and may cause allergic reactions among cleaning personnel.

Automation, including vacuum cleaners, steam cleaners, and floor scrubbers, enhances cleaning efficiency. Vacuuming before wet mopping reduces soil distribution during the mopping process. Scrubbing machines, frequently used in operating theaters, achieve superior cleanliness and provide longer-term microbiological benefits, although their use can be labor-intensive and cumbersome.

3. Critical Surfaces

Frequently touched items, such as telephones, light switches, computer keyboards, and medical equipment, present heightened risks of contamination and hand-based pathogen transmission. Enhanced cleaning and disinfection are often necessary for such high-touch surfaces. These surfaces can be identified through direct observation or environmental monitoring using fluorescent or other markers.

For example, a study conducted in 1999 inoculated a neonatal ICU telephone with a cauliflower mosaic virus DNA marker and monitored its spread to other hand-contact surfaces over a week. Approximately 58% of sampled sites in the same room as the inoculated telephone became contaminated, peaking at 78% after 8 hours before declining to 23% by the end of the week. Contamination was also observed in other rooms, with the most affected sites being personnel hands, computer keyboards, door handles, and medical charts. These findings underscore the importance of more frequent cleaning or disinfection for high-risk surfaces. Drawing parallels with hazard analysis critical control point (HACCP) systems in the food industry, such frameworks can identify and manage contamination risks.

Routine decontamination of near-patient hand-touch sites is typically outlined in institutional cleaning policies. Cleaning responsibilities may vary based on the type of surface or equipment, whether the patient is present, and whether the surface is electrical or nonelectrical (Bogusz et al., 2013). In intensive care units, where contamination with pathogens like MRSA reoccurs rapidly, high-touch surfaces may require cleaning more frequently than on general wards.

4. Clinical Equipment

Clinical equipment requires cleaning and disinfection before and after every use, irrespective of its frequency or location of use. Items such as commodes and reusable apparatus that contact blood or body fluids, including thermometers and pulse oximeters, must undergo stringent decontamination. Stethoscopes, which are frequently contaminated, should be wiped with alcohol, though compliance with such practices can be inconsistent, particularly during busy shifts (Dancer, 2012).

Audits often reveal significant contamination on clinical equipment, as demonstrated by an acute-care ward study where 84% of sampled items exceeded acceptable contamination benchmarks. The lack of clear cleaning responsibilities for certain equipment contributes to this issue, emphasizing the need for regular review and comprehensive staff training.

5. Terminal (Deep) Cleaning

Terminal cleaning is conducted after patient discharge and involves removing all objects from the room, cleaning surfaces from top to bottom, and disinfecting as necessary based on the pathogen involved. Curtains, drapes, and screens are typically removed for laundering, while fixed blinds are cleaned in situ. Clear guidelines on cleaning responsibilities among nurses, clinical support workers, and housekeeping staff are essential to avoid confusion and ensure thorough cleaning.

6. Microfiber Versus Cotton

While cotton cloths and mop heads remain common in hospitals, microfiber products, including ultramicrofiber (UMF) cloths, have gained popularity for their superior ability to remove pathogens. However, microfiber products are expensive and require careful decontamination to prevent pathogen adherence. Their cost-effectiveness should be weighed against traditional materials through thorough analysis (Mafu et al., 2013).

7. Contamination of Cleaning Equipment and Liquids

Contaminated cleaning equipment or liquids can compromise cleaning efficacy. For example, certain cleaning cloths may distribute rather than remove pathogens, while some cleaning fluids encourage bacterial resistance. Microbial niches left inadequately cleaned may allow genetic exchanges that promote antimicrobial resistance (Warnes et al., 2012).

8. Benefits of Physical Soil Removal

Evidence suggests that physical removal of soil plays a critical role in reducing microbial contamination, often outperforming biocidal disinfectants in certain conditions (Petti et al., 2013). Physical cleaning methods, such as detergent wiping, should be evaluated alongside biocides for their cost, long-term effectiveness, and environmental impact.

Automated Decontamination Devices

Recent advancements in cleaning practices aim to improve the effectiveness and scope of healthcare environmental hygiene, reflecting growing awareness of its importance. Inadequate cleaning or uncleaned surfaces may harbor residual bioburden, leading to the transmission of pathogens. To evaluate cleaning quality, Carling et al. applied a transparent gel to specific surfaces in over 1,000 patient rooms across 23 acute-care hospitals prior to cleaning. This gel, which fluoresces under UV light, is stable, nontoxic, difficult to detect, and easy to clean. When UV inspection reveals residual gel, it is presumed that the site was insufficiently cleaned. The study found an overall cleaning compliance rate of only 49% (ranging from 35% to 81%), based on the percentage of evaluated surfaces. Consequently, several manufacturers are developing automated room disinfection systems that utilize germicidal light, hydrogen peroxide, steam, or ozone to achieve superior decontamination.

While automated technologies enhance decontamination, they cannot replace routine daily cleaning. Organic matter, liquids, waste, and litter must still be removed from surfaces before applying disinfectant agents. These technologies are often restricted to terminal or discharge cleaning due to safety concerns, such as toxicity to patients (e.g., hydrogen peroxide) or risks associated with steam and UV light, making them more appropriate for use in empty rooms.

1. Steam Cleaning

Steam vapor machines have demonstrated rapid efficacy against pathogens like vancomycin-resistant enterococci (VRE), methicillin-resistant Staphylococcus aureus (MRSA), and Gram-negative bacilli, including Pseudomonas aeruginosa. Initial bacterial inocula of 7 log10 were reduced to undetectable levels in under 5 seconds of steam exposure. Steam cleaning reduces hospital surface bioburden by over 90% and nearly eliminates pathogens. Solid waste should be removed prior to steam application, but steam can be applied directly to a wide range of surfaces, both hard and soft.

Although studies on the efficacy of steam cleaning are limited, available data suggest benefits in routine and outbreak situations. For example, during an outbreak of norovirus in an Australian hospital, one ward was cleaned with detergent and bleach, while another used steam cleaning with microfiber cloths and mops for terminal cleaning. The steam cleaning protocol required fewer cleaning hours, eliminated the use of toxic chemicals, reduced water consumption by 90%, and achieved superior visual cleanliness. Staff expressed strong support for the steam-based method (Gillespie et al., 2013).

Despite its advantages, concerns remain regarding the routine use of steam technology in hospitals. Cleaning high-touch sites such as switches, knobs, and computers poses practical challenges. Steam temperature may dissipate rapidly depending on the surface, potentially reducing its efficacy. In one study, insufficient steam exposure during curtain cleaning left pathogens detectable before and after cleaning. Additionally, residual moisture from steam cleaning poses risks of slips and falls, although superheated steam minimizes water on exposed surfaces. Steam cleaning in crowded wards is also problematic due to restricted access to patient-adjacent areas and time constraints for cleaning. Equipment mishandling can result in burns or scalds, and steam inhalation may aggravate respiratory conditions in staff or patients. Steam cleaning has found utility in rolling programs for nonclinical areas and public hospital toilets, but comprehensive risk assessments are needed to address potential aerosolized pathogens from vaporization.

2. Ozone

Ozone, a powerful oxidizing agent, is effective against vegetative bacterial cells but less so against bacterial spores and fungi. While inexpensive to produce, ozone is toxic and potentially corrosive to metals and rubber, limiting its application in healthcare settings. One study demonstrated a 5 log10 reduction in Escherichia coli and total coliform counts in rinse water when ozone was used in hospital laundry systems. Ozone has also shown promise as a gaseous decontaminant for controlling Clostridioides difficile on surfaces, achieving reductions of >4 log10 with 25 ppm ozone for 20 minutes at 90% relative humidity. However, other studies reported only partial success, with 3 log10 reductions requiring longer exposure times.

In a domestic setting, 12 ppm ozone effectively eradicated MRSA from home surfaces. However, in hospital settings, ozone concentrations of 0.14 ppm failed to eliminate MRSA and caused respiratory symptoms in exposed staff. These findings highlight the need for cautious implementation of ozone-based disinfection in healthcare.

3. UV Light

UV irradiation, particularly UV-C light with wavelengths of 200–270 nm, has been explored for surface, instrument, and air disinfection due to its DNA-damaging effects. Factors such as exposure time, lamp positioning, barriers, and air flow influence UV-C efficacy. Studies have demonstrated significant reductions in C. difficile, VRE, and MRSA contamination on frequently touched surfaces using automated UV-C systems. Hand-held UV-C devices have shown similar pathogen reductions but were less effective in the presence of organic matter, emphasizing the need for preliminary cleaning.

Pulsed UV light systems have also reduced housekeeping time compared to manual disinfection with alcohol wipes. However, UV-C systems have limitations, including reduced efficacy for shaded or obstructed surfaces and potential damage to plastics and polymers with repeated use. The technology is recommended as a supplementary rather than primary decontamination strategy, especially in high HAI environments. Implementation considerations include costs, hospital layout, integration into cleaning protocols, and safety measures for operators.

4. High-Intensity Narrow-Spectrum (HINS) Light

HINS light uses visible violet light (405 nm) to inactivate microbes through photoexcitation of porphyrins, resulting in bactericidal compounds. Although one study showed its potential for clinical environment decontamination, further research is needed to assess its impact on HAI rates.

5. Hydrogen Peroxide (HP)

Hydrogen peroxide-based systems, available in vapor and aerosol forms, effectively reduce various hospital pathogens, including MRSA, VRE, and Acinetobacter spp. In one study, HP systems reduced CDI incidence in high-risk wards. However, these systems are costly, time-intensive, and require trained operators. HP efficacy is reduced by organic debris and surface irregularities, and repeated use may damage surfaces. Moreover, HP decontamination cycles can disrupt hospital operations, particularly in facilities with high occupancy rates (Dancer, 2013).

6. UV vs. HP Systems

UV-C systems provide faster decontamination cycles, making rooms available for patients sooner. However, HP systems exhibit superior sporicidal activity, particularly against C. difficile. These differences are influenced by exposure time and emission intensity, requiring further investigation. Both technologies reduce microbial contamination but face logistical and cost-related challenges.

Innovative technologies offer promising alternatives for hospital hygiene but require further independent studies to evaluate their cost-effectiveness and impacts on airborne pathogens. Premature adoption without comprehensive assessment could lead to inefficiencies.

Conclusion:

Environmental cleaning is a cornerstone of infection control in healthcare settings, yet its effectiveness depends on rigorous protocols, innovative technologies, and comprehensive training for cleaning personnel. Advances such as automated disinfection systems, including UV-C light, hydrogen peroxide vapor, and steam cleaning, offer promising enhancements to traditional manual methods. However, these technologies are not standalone solutions and must complement routine cleaning practices to address organic matter and other debris.

While evidence underscores the importance of cleaning in controlling healthcare-associated infections (HAIs), challenges remain in balancing cost, feasibility, and efficacy. Factors such as training, monitoring, and the integration of cleaning responsibilities across staff roles are critical for ensuring consistency. Additionally, antimicrobial stewardship and surface decontamination should operate synergistically to minimize pathogen transmission.

Future research should focus on evaluating the cost-effectiveness and long-term outcomes of innovative cleaning interventions, as well as their impact on reducing airborne pathogens. A multidisciplinary approach, encompassing infection control teams, policymakers, and cleaning personnel, is essential for optimizing hygiene practices and safeguarding patient health in diverse healthcare environments.

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