Continuously Active Disinfection: Minimizing the Role of Surface and Equipment Recontamination in the Transmission of Healthcare Pathogens

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Over the last decade, there has been a growing body of evidence that the healthcare environment and reusable patient care equipment become contaminated with epidemiologically important pathogens (EIP), which include, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), multidrug-resistant gram-negative bacilli (e.g. *Acinetobacter baumannii, Enterobacter species*) and norovirus, and contribute to the transmission of healthcare-associated infections (HAI) and outbreaks. The risk to patients is potentiated by the lack of adherence to standards for daily and terminal cleaning by Environmental Services (ES) staff and/or lack of adequate disinfection of shared medical equipment by nursing and ancillary staff. Even with optimal cleaning and disinfecting practices, recontamination of the environment and equipment occurs quickly by patient shedding as well as through contact with the hands and/or gloves of healthcare providers and by patient and visitor hands. For this reason, there has been interest in developing methods of continuous room disinfection. This white paper will review the currently available continuous room disinfection methods and introduce a novel continuously active disinfectant.

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Evidence that the contaminated environment plays a role in transmission of EIPs includes patient shedding of these organisms, prolonged environmental survival of these organisms from days to months, and transfer of the organisms to the hands of healthcare personnel (HCP) resulting in frequent recontamination of surfaces.[1] Multiple studies have shown that 10-50% of the surfaces in the rooms of patients colonized or infected with *C. difficile*, MRSA and VRE are contaminated with these pathogens and a lack of thoroughness of cleaning the contaminated surfaces in patient rooms (mean 32% of objects cleaned) has been linked to an overall 120% increase risk of infection to the next occupant in that room.[2,3] In a multivariate analysis conducted by Cohen and colleagues,[4] the odds of cases – defined as patients who acquired an HAI with selected EIPs - having been exposed to a prior bed occupant with the same organism were 5.83 times that of controls – matched on a 1:1 ratio to cases who had no positive cultures for the selected EIPs during their hospitalization - (95% confidence interval [CI], 3.62–9.39), and the odds of cases having been exposed to a roommate with the same organism were 4.82 times that of controls (95% CI, 3.67–6.34). The contribution of patient hands to environmental contamination with multidrug-resistant organisms (MDROs) was recently investigated with findings that 10% of newly admitted patients had an MDRO on their hands, 29% of rooms were contaminated within 24 hours of admission, and patient hand contamination was associated with patient room contamination with the same MDRO.[5] Although these studies highlight the need for improving the thoroughness of cleaning and disinfecting all hand-contact surfaces in patient rooms, an evaluation of terminal room cleaning in 23 acute care hospitals using a fluorescent marker monitoring technique found only 49% of surfaces to be thoroughly cleaned.[6] Interventional strategies used to improve cleaning processes include: monthly feedback of performance data based on fluorescent marker monitoring in face-to-face meetings with frontline ES personnel;[7] objective structured assessment of performance and education programs of ES staff by infection preventionists;[8] and formal multi-disciplinary education to ES, nursing and respiratory therapists emphasizing thorough cleaning practices with observation of ES staff performance.[9] Investigators have reported that intervention programs aimed at improving surface and equipment cleaning and disinfection have reduced pathogen acquisition and resolved outbreaks.[10] In addition to education and performance feedback, these programs included development of new protocols, delineation of cleaning responsibilities for specific items and use of checklists.

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Disinfection should render surfaces and equipment free of pathogens in sufficient numbers to prevent disease transmission.[11] Improved terminal disinfection (e.g., ultraviolet [UV]), which supplements surface disinfection, leads to a decreased rate of infection in patients subsequently admitted to the room where the prior occupant was colonized or infected. However, limitations of these "no touch" technologies include: an increase in room turnover time, need for trained and dedicated ES staff to transport and operate the equipment and importantly, safety requirements require removal of the patients, visitors and HCP from the room during use of the equipment. Further, microbial contamination of environmental surfaces and reusable patient care items occurs continuously via patients, visitors and staff. Routine (e.g., daily) disinfection practices render surfaces and equipment hygienically clean but not sterile. If an antimicrobial residue was left on surfaces and equipment by a disinfectant with persistent activity for 24 hours, environmental control of EIPs preventing recontamination would be achieved.

Recontamination of Surfaces and Patient Care Equipment

Transmission of EIPs occurs when gloves and/or hands become contaminated through contact with the environment or during patient care and results in transfer of pathogens to another patient and/or the environment. Additionally, the patient can self-inoculate when their hands become contaminated from touching the environment. A meta-analysis examining transfer of pathogens from patients and their environment to HCP hands, gloves, and gowns found an estimated proportion for transfer frequency of 33% (95% confidence interval [CI], 12%–57%), 30% (95% CI, 23%–38%) and 10% (95% CI, 6%–14%), respectively.[12]

Many studies have demonstrated that patient care rooms are not always cleaned and disinfected thoroughly. Even with standardized training, variation in room cleaning practices has been observed among ES staff.[13] An examination of the relationship between the amount of time spent by an ES worker cleaning a hospital room and the thoroughness of surface removal of a fluorescent marker did not reveal a correlation.[14] In an AHRQ sponsored study, Han and colleagues[15] reviewed 4 systematic reviews and 76 primary studies of environmental cleaning and found that the thoroughness of cleaning or adherence to the manufacturers' recommendations for proper use of disinfectants was frequently not reported. They concluded that the use of fluorescent markers on surfaces to provide ES performance feedback improved cleaning practices; however, improvement was not sustained without on-going education, direct feedback, and commitment and flexibility of administrative leaders.

The "no touch" room decontamination systems, e.g. UV light and hydrogen peroxide systems, which are not dependent on human performance and perceptions associated with manual cleaning technique, have become important adjunct technologies to improve the thoroughness of cleaning and disinfection processes. Many studies have demonstrated that UV and hydrogen peroxide systems can inactivate microbes on carrier materials when placed in hospital rooms and disinfect surfaces in hospital rooms which are naturally contaminated with MDROs. Over a dozen clinical trials have demonstrated that UV devices and hydrogen peroxide systems, when used for terminal disinfection, can reduce HAIs in patients admitted to these contaminated hospital rooms.[16] In a sub-study of the Benefits of Enhanced Terminal Room (BETR) Disinfection Study[17] an analysis of additional microbiological data was conducted to assess the effectiveness of 3 enhanced methods of room decontamination (i.e., quaternary ammonium manual disinfection [Quat] followed by UV, bleach, or bleach plus UV) compared to a standard method (i.e., Quat alone) to reduce the level of surface contamination with 4 EIPs (multidrug-resistant [MDR] *Acinetobacter*, *C. difficile*, MRSA, VRE). Quat plus UV was significantly superior to Quat alone (standard method) resulting in a decrease in room contamination with EIPs of 94% which was associated with a 35% decrease in subsequent patient colonization and/or infection.[18]

Patient rooms that have been terminally cleaned may still be contaminated with MDROs. In another BETR sub-study with the objective of characterizing the nature of MDRO transmission between the environment and patients, Chen and colleagues[19] enrolled 80 patient-room admissions in rooms that previously housed patients with 1 of 4 MDROs: MRSA, VRE, *C. difficile* and MDR-*Acinetobacter baumannii*. Significant findings included: 11.3% of admitted patients were asymptomatically colonized with an MDRO, 55% of the rooms had surfaces contaminated with MDROs despite terminal disinfection and microbiological bacterial transfer events between patients and the environment were observed in 18.5% of patient encounters and occurred early in the admission.[19] In an evaluation of rooms occupied by patients with MDR-*Acinetobacter baumannii* colonization or infections, 46.9% of rooms and 15.3% of sites were found contaminated pre-cleaning, and 25% of rooms and 5.5% of sites were found contaminated post-cleaning.[20] A multi-center prospective microbiological survey of MDRO contact precaution rooms, undertaken to determine the typical microbial bioburden of MDROs on high-touch surfaces after routine or terminal cleaning, identified that *C. difficile* was the predominately recovered organism from terminally cleaned rooms and that 50% of the *C. difficile* isolates were recovered from non-*C. difficile* rooms.[21]

Reusable patient care items have also been identified as a source or reservoir for healthcare-associated pathogens. A review by Kanamori and co-workers[22] demonstrated a variety of healthcare-associated outbreaks via a patient care item due to bacterial pathogens, as well as increasing reports of fomite-associated outbreaks due to MDROs, and identified inappropriate disinfection practice for shared items as the main cause of these outbreaks. A quantitative assessment found that hospitalized patients frequently had interactions with shared portable medical equipment, most of which had direct contact with patients (e.g, wheelchairs, bladder scanners) and identified that 12% of cultured equipment was contaminated with MRSA, VRE, or *C. difficile*.[23] Havill et al.[24] evaluated the cleanliness of portable equipment used by nursing for vital sign monitoring using adenosine triphosphate (ATP) bioluminescence assays and aerobic colony counts (ACC) and concluded the detected levels of organic soil and ACCs suggested that cleaning and disinfecting protocols were not being followed.

Continual recontamination of environmental surfaces and reusable patient care equipment is multifactorial. The prolonged survival of EIPs, the level of contamination of rooms related to pathogen shedding from both symptomatic and asymptomatic patients with EIPs, suboptimal cleaning processes by ES staff and suboptimal hand hygiene practices by HCPs and patients are all contributory factors. The conundrum for the infection prevention community is how to reliably and consistently have hygienically clean surfaces and equipment to enhance patient safety. Currently, that safety is predominantly dependent on ES staff and HCP performing adequate cleaning and disinfecting processes and practicing optimal hand hygiene.

Continuous Room Decontamination Technology

Advancing technology has introduced new methods to address surface and equipment recontamination to prevent environment-mediated acquisition of healthcare-associated pathogens. Currently, there are several available technologies: visible light disinfection through light-emitting diodes (LEDs); low concentration hydrogen peroxide; and self-disinfecting surfaces. These continuous room decontamination technologies are safe to use in occupied patient rooms.

Visible light disinfection uses LEDs to create a narrow bandwidth of high intensity visible violet light with a peak output of 405 nm which in turn reacts with porphyrin molecules to generate reactive oxygen species that kill microorganisms without harming human cells. It does not affect materials and provides continuous disinfection when in use. Rutala and co-workers[25] performed a preliminary evaluation of the technology and demonstrated that the high irradiant light significantly reduced the 3 vegetative test bacteria and yielded lower counts of *C. difficile* spores at some time points over 72 hours. Murrell et. al.[26] reported that visible-light disinfection systems used in orthopedic operating rooms yielded a decrease in microbial surface contamination as well as a decrease in surgical site infections. In addition to determining the cost-effectiveness, effect on multiple surface types, areas of use and acceptance of 24-hour continuous light by patients and staff, future studies should include re-challenging the surfaces with additional contamination (e.g., every 4–6 hours) to simulate the real world clinical environment.[25]

Low-dose hydrogen peroxide gas (e.g., 0.1 ppm) is considered a potential method for continuous room decontamination. Rutala and co-workers[27] used a dilute hydrogen peroxide (DHP) device for continuous room decontamination and experimentally examined the germicidal efficacy of this new technology against three test organisms – MRSA, VRE and MDR-*Acinetobacter baumannii* - in a model patient room. This preliminary study demonstrated inactivity against the MDROs on room surfaces, with the authors concluding that the findings were likely due to an inability to generate a sufficient germicidal level under their test conditions with the particular DHP units.

Reduction of contamination on surfaces has also been accomplished by surface coating with a heavy metal, such as silver and copper. In a crossover trial conducted in an ICU with MDRO endemicity, copper-coating significantly reduced the percentage of colonized surfaces, the percentage of surfaces colonized by MDR-gram-negative bacteria or enterococci, and the numbers of total viable bacterial colonies and of gram-negative colonies.[28] In a randomized trial by Salgado et al.[29], copper coating reduced the rate of HAIs and/or colonization by MRSA or VRE in the copper coated rooms.

Continuously Active Disinfectants (CADs)

Commonly used disinfectants (e.g., improved HP, bleach) do not have persistent residual activity. In 2013, Tamimi and co-workers[30] evaluated in an ICU setting the efficacy of a quaternary ammonium organosilane formulation that had been shown to bind to surfaces producing residual disinfecting activity. Surfaces were cultured prior to treatment and at 1, 2, 4, 8, and 15 week intervals after the application of the CAD product. The average bacterial count on all surfaces was reduced by greater than 99% (>2 $\log_{10}$ reduction) for at least 8 weeks after treatment. Overall, bacterial counts never returned to the original count even after 15 weeks. MDROs were found on 25% of the tested sites prior to treatment and only 1 isolate was found at 15 weeks post-treatment.[29]

Rutala and associates[31] investigated the efficacy of a newly developed CAD. After application, this persistent surface disinfectant demonstrated a 4-5 $\log_{10}$ reduction in 5 minutes over 24 hours for most pathogens. The EIPs tested were *S. aureus*, VRE, *E. coli, Enterobacter sp., Candida auris, Klebsiella pneumoniae*, carbapenem-resistant (CR) *E. coli*, CR *Enterobacter*, and CR *K. pneumoniae*. This study showed approximately 99% reduction with *Klebsiella* and CR *Enterobacter*. The novel CAD was compared to three other commonly used health care disinfectants employing the same methodology with *S. aureus*. The novel CAD outperformed all of the other disinfectants. The mean $\log_{10}$ reductions were impressively different.(Table 1).

Table 1 Comparison Between Disinfectants[31]

Test Disinfectant	Mean $\log_{10}$ Reduction
Novel Disinfectant (CAD)	4.4
Quat-Alcohol	0.9
Improved Hydrogen Peroxide	0.2
Chlorine	0.1

A recently published *in situ* evaluation of two EPA-registered quaternary ammonium disinfectants and a trial disinfectant with persistent activity (same CAD product evaluated by Rutala et al.[31]) was conducted to assess their ability to limit bioburden subsequent to application on the bedrails of patients in an ICU.[32] Prior to application of the disinfectants, resident microbial bioburden was assessed in occupied beds. Bioburden was recovered and enumerated immediately prior to application of the disinfectants and at 1, 6 and 24 hours subsequent to application. The continuous disinfection activity of the CAD was evident with bioburden significantly lower at 1, 6 and 24 hours post-disinfection when compared to the other disinfectants tested.

The novel CAD is the first and only EPA-registered surface disinfectant with 24 hours sustained antimicrobial activity. It has a 1-minute contact time for a broad spectrum of microorganisms and a 5-minute contact time for continuously active disinfection and is compatible with a large variety of materials such as plastic, upholstery, vinyl, aluminum, and glazed ceramics.

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Summary

CADs and other continuous room decontamination technologies may reduce or eliminate the problem of recontamination and minimize the role of contaminated environmental surfaces and equipment in transmission of healthcare pathogens and prevent HAIs. Further, the use of a CAD will improve the efficiency of ES staff and HCP with responsibility for cleaning and disinfecting reusable patient care equipment with application required only once every 24 hours.

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