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Does improving surface cleaning and disinfection reduce health care-associated infections?

Curtis J. Donskey MD [a,b,*]

[a] Geriatric Research, Education, and Clinical Center, Cleveland Veterans Affairs Medical Center, Cleveland, OH
[b] Case Western Reserve University School of Medicine, Cleveland, OH

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Contaminated environmental surfaces provide an important potential source for transmission of health care-associated pathogens. In recent years, a variety of interventions have been shown to be effective in improving cleaning and disinfection of surfaces. This review examines the evidence that improving environmental disinfection can reduce health care-associated infections.

Contaminated environmental surfaces provide an important potential source for transmission of many health care-associated pathogens.[1-6] These include *Clostridium difficile*, methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), gram-negative bacilli (eg, *Acinetobacter baumannii* and *Pseudomonas aeruginosa*), and norovirus.[1-6] In recent years, a number of studies have demonstrated that environmental cleaning interventions can improve the thoroughness of cleaning and reduce contamination on surfaces.[7-11] This review examines the evidence that such improvements in environmental disinfection may prevent transmission and reduce health care-associated infections. The review was not conducted as a systematic review, but the MEDLINE electronic database was searched using broad search terminologies and recent review articles, and their references were searched. Studies were included only if the impact of the intervention on rates of pathogen acquisition and/or infection was assessed and environmental cleaning and disinfection was the primary focus of an intervention (ie, Multifaceted infection control interventions were not included unless environmental disinfection was a central component of the intervention).

ENVIRONMENTAL DISINFECTION STRATEGIES

Figure 1 provides an overview of common routes of transmission of health care-associated pathogens. Patients colonized or infected with health care-associated pathogens shed organisms onto their skin, clothing, bedding, and nearby environmental surfaces.[12] In addition to surfaces in rooms, portable equipment and other fomites often become contaminated after contact with patients or contaminated surfaces.[12-14] Susceptible patients may acquire pathogens through direct contact with contaminated surfaces or equipment or via the hands of health care personnel that have become contaminated after contact with patients or environmental surfaces.[15-17] For many pathogens, a majority of patients acquiring colonization do not develop clinically apparent infections. These asymptomatic carriers may shed pathogens into the environment and contribute to transmission.[18,19]

Based on these routes of transmission, Figure 1 highlights 4 potential environmental disinfection strategies to reduce transmission. First, improving cleaning and disinfection of rooms of patients known to carry health care-associated pathogens after discharge (ie, terminal cleaning) will reduce the risk that patients subsequently admitted to the same room will acquire pathogens from contaminated surfaces.[20] Second, daily disinfection of high-touch surfaces in isolation rooms may be useful to reduce the risk of contamination of the hands of health care personnel providing care for the patients.[21,22] This strategy is analogous to daily disinfection of the skin of patients as a means of source control to reduce transmission of MRSA and VRE.[23,24] Third, disinfection of portable equipment between patients or use of disposable equipment in isolation rooms will reduce the risk for transmission.[13,14] Finally, rather than focusing only on isolation rooms, efforts to improve cleaning and disinfection of all rooms may be beneficial if there is a concern that many carriers are not identified or are identified only after long delays.[19,25]

Many environmental disinfection interventions reported in the literature have focused primarily on improving terminal cleaning of

* Address correspondence to Curtis J. Donskey, MD, Geriatric Research Education and Clinical Center, Cleveland VA Medical Center, 10701 East Boulevard, Cleveland, OH 44106.

E-mail address: curtisd123@yahoo.com.

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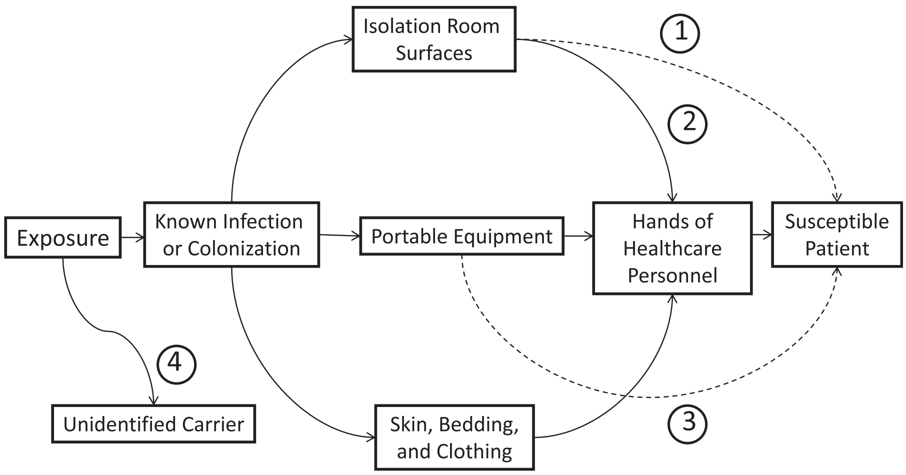

Fig 1. Overview of common routes of transmission of health care-associated pathogens and potential environmental disinfection strategies (adapted from Donskey[12]). Patients colonized or infected with health care-associated pathogens shed organisms onto their skin, clothing, and nearby environmental surfaces. Susceptible patients may acquire pathogens through direct contact with surfaces or equipment or via the hands of health care personnel. Four sources of transmission and potential environmental disinfection strategies to interrupt transmission are shown: (1) contamination of surfaces after terminal cleaning of isolation rooms resulting in risk of acquisition by patients subsequently admitted to the same room (intervention: improve terminal room cleaning and disinfection); (2) contamination of surfaces in isolation rooms resulting in risk for contamination of health care personnel hands (intervention: daily disinfection of high-touch surfaces); (3) contamination of portable equipment (intervention: disinfection of portable equipment between patients or use of disposable equipment in isolation rooms); and (4) contamination of surfaces in rooms of unidentified carriers of health care-associated pathogens (intervention: improve cleaning and disinfection of all rooms on high-risk wards or throughout a facility).

isolation rooms. It is plausible that more comprehensive interventions that include daily disinfection of high-touch surfaces, disinfection of portable equipment, and improved cleaning of nonisolation rooms might be most effective. However, studies have rarely compared the effectiveness of different disinfection strategies or combinations of strategies. When available, information on the different strategies included in disinfection interventions is included in this review.

ENVIRONMENTAL DISINFECTION INTERVENTIONS

Overview

Environmental disinfection interventions range from simple interventions involving substitution of one disinfectant product for another to intensive efforts to improve cleaning performance through education plus monitoring and feedback to housekeepers. In this regard, disinfection interventions are analogous to antimicrobial stewardship interventions, which range from formulary substitutions to formal stewardship programs that include monitoring and feedback. For the purposes of this review, disinfection interventions were divided into 3 categories: (1) disinfectant product substitutions (ie, Although efforts may be undertaken to improve cleaning, the primary intervention is a change to a disinfectant with improved effectiveness against a particular pathogen), (2) interventions to improve effectiveness of cleaning and disinfection practices, and (3) use of automated disinfection technologies. In practice, disinfectant product substitutions have most often involved substitution of sporicidal for nonsporicidal products as a control strategy for *C difficile*. Interventions to improve effectiveness of cleaning and disinfection have more often been implemented for control of pathogens that are susceptible to a wide range of disinfectants (eg, MRSA, VRE, and gram-negative bacilli). Studies were included in this review if the impact of the intervention on rates of acquisition and/or infection was assessed.

It should be appreciated that the studies reviewed here could potentially underestimate or overestimate the real-world benefits of environmental disinfection interventions. On one hand, environmental disinfection is often included as one component of multifaceted infection control interventions. Many such successful interventions are not included in this review because the contribution of environmental disinfection to the overall success of the programs is uncertain.[26-30] On the other hand, the published literature might provide an overly optimistic assessment of the impact of environmental disinfection interventions. Many institutions have implemented environmental disinfection interventions without reducing colonization or infection with health care-associated pathogens but have not published their findings (author's unpublished data). Successful interventions are more likely to be submitted for publication than those that fail.

Disinfectant product substitutions

Table 1 provides an overview of 7 studies that involved disinfectant substitutions.[25,31-36] In one intervention, an active oxygen-based compound was substituted for a detergent for daily cleaning of floors and furniture, and a quaternary ammonium compound was continued for floors on a second ward.[31] The active oxygen-based product was associated with better eradication of bacteria from surfaces but no reduction in nosocomial bloodstream infections or MRSA colonization and infection. In the other interventions, hypochlorite was substituted for a nonsporicidal product as a strategy to control *C difficile*. The concentration of hypochlorite ranged from 500 to 5,500 parts per million (ppm). In each of the *C difficile* infection (CDI) interventions, there was a reduction in infections on 1 or more wards. Mayfield et al[33] found that CDI rates decreased significantly on a bone marrow transplant with a relatively high endemic incidence of CDI but not on a medical ward or intensive care unit with lower baseline rates. Similarly, in a crossover study on 2 medical wards in a nonoutbreak setting, Wilcox et al[34] found that the incidence of CDI decreased only on the ward with the higher baseline CDI rate. These results suggest that environmental disinfection interventions may have greater impact in settings where the baseline incidence is high. However, Hacek et al[36] reported a significant reduction in CDI incidence from a relatively low endemic baseline rate when hypochlorite was substituted for a quaternary ammonium product in 3 hospitals.

Reductions in CDI were achieved with a variety of disinfection strategies. Kaatz et al[32] ended a CDI outbreak on a medical ward by

Table 1
Studies involving disinfectant product substitutions

Ref	Setting and organism	Product	Practice	Monitoring of disinfection	Effect
31	2 Hospital wards Nosocomial infections	Active oxygen-based compound	Daily cleaning of floors and furniture	Cultures: decreased bacterial load on surfaces	No reduction in bloodstream infections or MRSA colonization or infection
32	Medical ward *Clostridium difficile*	Hypochlorite 500 ppm	Terminal CDI rooms	Cultures: surface contamination decreased to 21% of initial levels	Outbreak ended
33	Bone marrow transplant (BMT) unit, Medical Ward, ICU *Clostridium difficile*	Hypochlorite 5,000 ppm	Terminal CDI rooms	No	Significant decrease on BMT unit but not on the other 2 wards
34	2 Medical wards (crossover study) *Clostridium difficile*	Hypochlorite 1,000 ppm	Terminal CDI rooms	Cultures: no decrease in the percentage of positive environmental cultures	Decreased on 1 of 2 wards
35	Medical and surgical ICUs *Clostridium difficile*	Hypochlorite 5,000 ppm	Ward 1: terminal CDI rooms; ward 2: all rooms	No	Decreased on both units
36	3 Hospitals *Clostridium difficile*	Hypochlorite 5,000 ppm	Terminal CDI rooms	No	48% decrease in prevalence density of CDI
25	2 Medical wards *Clostridium difficile*	Hypochlorite 5,500 ppm (wipes)	Terminal and daily CDI and non-CDI rooms	Yes (ATP bioluminescence)	85% decrease in hospital acquired CDI

ATP, Adenosine triphosphate; *BMT*, Bone marrow transplant; *CDI*, *C difficile* infection; *ICU*, intensive care unit; *PPM*, parts per million; *Ref*, reference number.
NOTE. 5,000 ppm = 1:10 dilution of household bleach.

disinfecting the entire unit with hypochlorite. Orenstein et al[25] achieved an 85% reduction in hospital-acquired CDI when hypochlorite wipes were used for daily and terminal disinfection of CDI and non-CDI rooms on 2 medical wards. However, McMullen et al[35] found that CDI rates decreased on a unit that used hypochlorite for all rooms and on a second unit that used hypochlorite only for CDI rooms. In the other 3 reports, reductions in CDI were achieved with use of hypochlorite for terminal disinfection of CDI rooms. These results suggest that it may be sufficient to focus disinfection efforts on CDI rooms.

Six of the 7 interventions in Table 1 were quasiexperimental studies in which rates were compared before and after interventions with no concurrent control group. Quasiexperimental studies are subject to a number of limitations, including difficulty in controlling for confounding factors and regression to the mean.[37] In the studies reviewed, a number of potential confounding factors were not reported. For example, compliance with hand hygiene or contact precautions could impact infection or colonization rates, but detailed information on these measures was not provided in any of the studies. Of the studies reviewed, the intervention of Mayfield et al[33] unintentionally achieved a higher study design quality by having a repeated-treatment design. As shown in Figure 2, the incidence of CDI decreased when hypochlorite was substituted for a quaternary ammonium product, increased again when the quaternary ammonium product was reinstituted in response to an increase in VRE infections, and finally was again reduced with reinstitution of hypochlorite.[33]

An important limitation of many of these studies is the absence of adequate monitoring to ensure that disinfectants were being applied effectively. In 3 of the 6 CDI studies, no routine monitoring of cleaning performance was reported. Only 2 of these studies included the use of environmental cultures to assess the impact of the intervention on surface disinfection. Kaatz et al[32] demonstrated a significant reduction in environmental contamination on the outbreak ward after hypochlorite disinfection of the ward. In contrast, Wilcox et al[34] performed monthly surveillance cultures and found that no reduction in the frequency of contamination of environmental surfaces or health care personnel' hands during periods when hypochlorite was substituted for a nonsporicidal detergent (Fig 3). These culture results raise concerns that the application of hypochlorite might have been suboptimal.

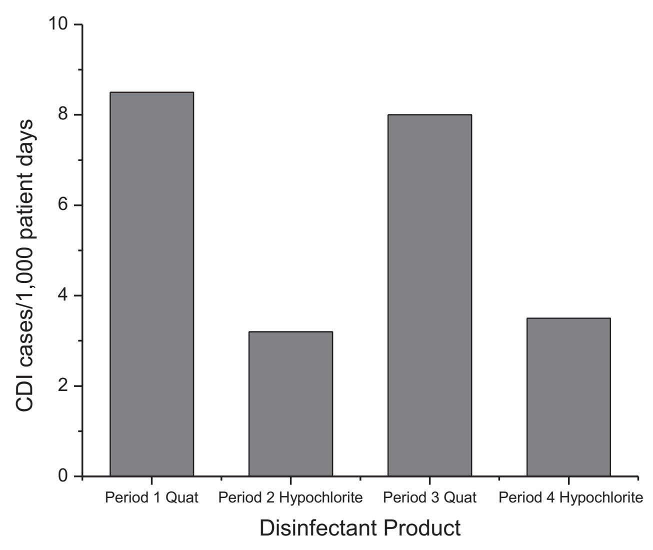

Fig 2. Incidence of *Clostridium difficile* infection (CDI) on a bone marrow transplant unit during periods when different disinfectant products were used (adapted from Mayfield et al[33]). The 4 periods included the following: (1) period 1: quaternary ammonium disinfectant; period 2: bleach containing 5,000 parts per million hypochlorite used for CDI rooms; period 3: quaternary ammonium disinfectant used daily for all rooms in response to an outbreak of vancomycin-resistant enterococci; and period 4: reinstitution of bleach for CDI rooms. Quat, quaternary ammonium disinfectant.

Interventions to improve effectiveness of cleaning and disinfection practices

Table 2 provides an overview of 9 studies in which interventions were implemented to improve effectiveness of cleaning and disinfection practices.[11,22,38-44] In 7 of the 9 interventions, pathogen acquisition was reduced or an outbreak resolved. Notably, Datta et al[39] demonstrated that MRSA acquisition was reduced by 62% and VRE by 22% for patients admitted to a room previously occupied by a patient colonized by the same pathogen. The interventions included a variety of different cleaning strategies. Several interventions emphasized daily disinfection and/or disinfection of

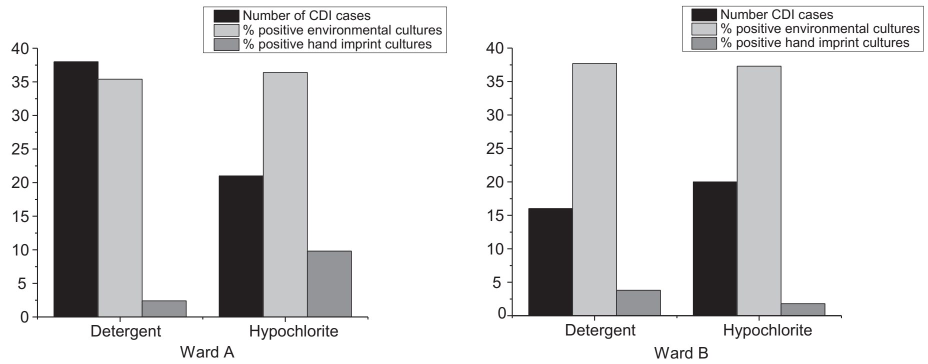

Fig 3. *Clostridium difficile* infections (CDI) and frequency of environmental contamination and hand contamination of health care personnel on 2 wards participating in a crossover study of hypochlorite versus neutral detergent for environmental disinfection. The incidence of CDI decreased during the hypochlorite period on ward A but not on ward B. There was no reduction in the frequency of contamination of environmental surfaces or health care personnel' hands during the hypochlorite periods.

Table 2
Studies involving interventions to improve effectiveness of cleaning and disinfection

Ref	Setting and organism	Design	Intervention	Monitoring of disinfection	Effect
38	Burn ICU VRE	Quasiexperimental	Twice-daily cleaning of all rooms, training of housekeepers, dedicated housekeeper for the unit, and use of checklists to guide cleaning	Decreased environmental contamination	Outbreak ended
11	Medical ICU VRE	Quasiexperimental	Education plus monitoring and feedback to improve daily and terminal cleaning	Decreased environmental contamination (10% to 3%-4% sites positive) and hand contamination (55% to 10%-11%)	Decreased VRE acquisition (hazard ratio, 0.36)
39	10 ICUs VRE & MRSA	Quasiexperimental	Feedback using fluorescent markers and bucket cleaning method with focus on terminal cleaning	Decreased contamination with MRSA or VRE after cleaning (27% vs 45% of rooms after cleaning)	Decreased acquisition of MRSA by 49% and VRE by 29%
40	ICU *A baumanii*	Quasiexperimental	Product substitution (hypochlorite [1,000 ppm replaced detergent]), new cleaning protocols, additional cleaning staff	Decreased environmental contamination	Outbreak ended
41	Surgical ward MRSA	Quasiexperimental	Entire ward disinfected, increased cleaning 57 hours per week including shared equipment and removal of dust, new protocols	Decreased environmental contamination from 11% to 0.7%	Decreased MRSA acquisition
42	2 Surgical wards MRSA	Ward-level crossover design	One additional cleaner disinfected high-touch surfaces in patient rooms 2-3 times/day and portable equipment and the nurse's station	Decreased aerobic microbial contamination by 33%, but no decrease in environmental MRSA	Decreased MRSA acquisition by 27%
43	Hospital *C difficile*	Quasiexperimental	Education; product substitutions (1st: hypochlorite; 2nd: 7% accelerated hydrogen peroxide); comprehensive ward disinfection when ≥3 nosocomial CDI cases	No	No decrease in CDI incidence
22	2 ICUs MRSA	1 Year randomized crossover study	Twice-daily enhanced cleaning of high-touch surfaces with ultramicrofiber cloths and a copper-based biocide; addition of a team of trained hygiene technicians	Decreased MRSA contamination in environment (15% vs 9%) and physician hands (3% vs 0.7%)	No decrease in MRSA acquisition (adjusted odds ratio, 0.98)
44	Hospital VRE	Quasiexperimental	Product substitution (hypochlorite 1,000 ppm), daily disinfection of all rooms, employment of cleaning supervisors, formal training plus monitoring and feedback, and 3-times yearly "super-clean-disinfection" of high-risk wards	Decreased VRE contamination by 66%	Decreased newly recognized VRE colonization by 25% and VRE bacteremia by 83%

A baumannii, Acinetobacter baumannii; *C difficile*, Clostridium difficile; *CDI*, C difficile infection; *ICU*, intensive care unit; *MRSA*, methicillin-resistant Staphlococcus aureus; *Ref*, reference number; *VRE*, vancomycin-resistant Enterococcus.

portable equipment in addition to terminal cleaning and disinfection. In addition to education of housekeepers, many of the interventions included development of new protocols or checklists and designation of responsibility for cleaning of specific items. Moreover, 5 of the interventions included providing designated housekeepers and/or hiring new housekeepers or supervisors.

A major strength of this group of studies is that cultures were routinely monitored in 8 of the 9 interventions, and reductions in environmental contamination were confirmed. In addition, some studies routinely assessed cleaning using methods such as direct observation of housekeeper performance or evaluation of fluorescent marker removal as a measure of thoroughness of cleaning. The

Table 3
Studies involving use of vaporized hydrogen peroxide for ward and/or terminal room disinfection

Reference	Setting/organism	Intervention	Monitoring of disinfection	Effect
45	Hospital-wide *Clostridium difficile*	CDI rooms	No	Outbreak ended
46	Long-term acute care *Acinetobacter baumannii*	Affected patient rooms	Decrease sites positive (8.6% to 0%)	Outbreak ended
47	Neonatal ICU *Serratia marcescens*	Entire unit	No *Serratia* recovered after hydrogen peroxide vapor	Outbreak ended
48	12-Bed ICU MDR-GNR	All ICU rooms	Decrease sites positive (47.6% to 0%)	No MDR-GNR cases for 2 months but recurrent cases at 3-4 months
49	Hospital-wide *Clostridium difficile*	Intensive decontamination of 5 high-incidence wards	Decrease sites positive (25.6% to 0%)	Significant decrease in CDI incidence on the high-incidence wards
50	6 High-risk wards (3 hydrogen peroxide vapor and 3 control wards) MDROs	Terminal MDRO rooms	Decreased contamination (relative risk, 0.65)	64% Decrease in MDRO acquisition; 80% decrease in VRE acquisition

ICU, Intensive care unit; *MDR-GNR*, multidrug-resistant gram-negative rods; *MDRO*, multidrug-resistant organisms.

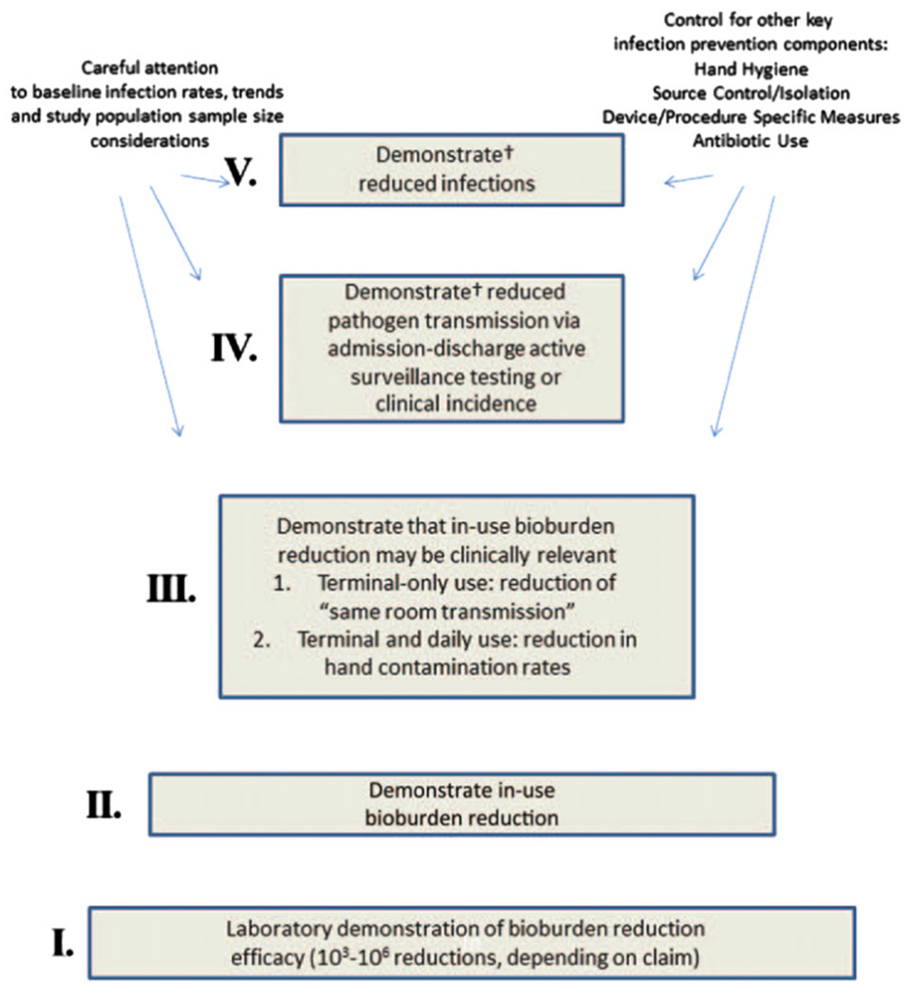

Fig 4. Evidence hierarchy for increasing patient safety through health care environmental surface cleaning and disinfection (Reprinted with permission from McDonald and Arduino[63]). †Prioritize cluster randomization over interupted time series design.

reduction in environmental contamination adds a degree of microbiologic plausibility to the subsequent decreases in pathogen acquisition. Moreover, the finding that specific sites were contaminated could sometimes be used to identify specific reservoirs for transmission and to direct disinfection efforts. For example, Falk et al[38] found that instruments used on patients were often contaminated, including a contaminated electrocardiogram lead that was implicated in reintroduction of VRE to the burn intensive care unit after initial success in controlling an outbreak.

One notable observation from these studies is that it may not be necessary to "get to zero" environmental contamination to reduce pathogen acquisition. For example, Datta et al[39] achieved a significant reduction in MRSA and VRE acquisition despite a 27% frequency of room contamination with MRSA or VRE after cleaning (improved from 45% at baseline). Similarly, Hayden et al[11] reduced VRE acquisition despite finding that 3% to 4% of sites cultured remained positive for VRE after cleaning (improved from 10% at baseline).

In 2 of the studies shown in Table 2, cleaning interventions failed to reduce the incidence of colonization or infection with pathogens. First, Valiquette et al[43] found that an intensive effort to improve environmental disinfection was ineffective in controlling an outbreak of CDI. The intervention included disinfectant substitutions to hypochlorite and then 7% accelerated hydrogen peroxide; the product used prior to hypochlorite was not specified. Limitations of the study were that no standardized monitoring of cleaning performance was reported, and cultures were not collected to assess effectiveness of disinfection. Notably, implementation of an antimicrobial stewardship program subsequently resulted in control of the outbreak. Second, in a well-designed randomized trial on 2 intensive care units, Wilson et al[22] found that enhanced twice-daily disinfection of hand contact surfaces reduced environmental and health care worker hand contamination but did not reduce patient acquisition of MRSA. The authors concluded that enhanced cleaning as defined in the study was not cost or clinically effective. One consideration in evaluating the contrast between these findings and the other studies in Table 2 is that the standard cleaning protocols on the control study wards appeared to be relatively high in quality (ie, routine daily cleaning, clear designation of cleaning responsibilities including a signed log, use of a chlorine-based product for isolated patients, regular monitoring of compliance with cleaning). It is plausible that enhanced cleaning interventions might have greater impact on pathogen acquisition in settings with lower quality baseline cleaning practices.

Automated disinfection devices

Automated devices that have been shown to be effective in reducing environmental contamination in hospital rooms include hydrogen peroxide vapor or aerosol devices and ultraviolet radiation devices. Of these, only hydrogen peroxide vapor has been evaluated for potential reduction in pathogen acquisition or infection (Table 3).[45-48] In several reports, hydrogen peroxide vapor has been used in outbreak settings and has been associated with reductions in colonization or infection with pathogens.[48-50] In an outbreak setting in a university-affiliated hospital, Boyce et al[49] demonstrated that use of hydrogen peroxide vapor for terminal disinfection of CDI rooms plus decontamination of high-incidence wards was associated with a significant reduction in the incidence of CDI. In another recent publication, Passaretti et al[50] compared multidrug-resistant organism (MDRO) acquisition in MDRO isolation rooms disinfected with hydrogen peroxide vapor versus standard cleaning. The study was conducted on 6 high-risk wards; the wards were not randomized, but 3 were chosen for use of hydrogen peroxide vapor for MDRO rooms on the ward when feasible. Use of hydrogen peroxide vapor was associated with a 64% reduction in acquisition of any MDRO and an 80% reduction in acquisition of VRE.

Disinfection or elimination of contaminated equipment

In addition to room disinfection, numerous outbreaks have been associated with contamination of equipment.[13,14,51-56] These outbreaks have been attributed to equipment such as ultrasonic nebulizers,[51] hydrotherapy equipment,[52] and electronic thermometers.[13,14,53] Disinfection or replacement of contaminated equipment has been effective in eliminating outbreaks. In 3 studies, replacement of reusable electronic thermometers with disposable thermometers was associated with significant reductions in CDI or VRE colonization.[13,14,53]

CONCLUSION

In 2004, Dettenkofer et al[57] performed a systematic review of the impact of environmental surface disinfection interventions on occurrence of health care-associated infections. The authors concluded that the quality of the studies existing at that time was poor, and none provided convincing evidence that disinfection of surfaces reduced infections. As reviewed here, during the past decade a growing body of evidence has accumulated suggesting that improvements in environmental disinfection may prevent transmission of pathogens and reduce health care-associated infections. Although the quality of much of the evidence remains suboptimal, a number of high-quality investigations now support environmental disinfection as a control strategy. Based on these data, current guidelines for pathogens such as *C difficile*, MRSA, VRE, and norovirus emphasize the importance of environmental disinfection as a control measure.[58-62]

Although current studies support environmental disinfection, there remains a need for carefully conducted studies to determine the impact of disinfection interventions. McDonald and Arduino have proposed an evidentiary hierarchy for assessing new disinfection interventions (Fig 4), with evaluations progressing from laboratory studies through cluster randomized trials.[63] Ultimately, data from randomized trials will be essential to confirm the findings of lower level studies. Studies are also needed to clarify several other important issues related to environmental disinfection interventions. First, do strategies such as daily disinfection of high-touch surfaces and increased attention to disinfection of portable equipment add significant benefit as adjuncts to terminal room cleaning? Second, if daily disinfection is performed, what is the optimal frequency of disinfection (daily or more often)? Third, is it beneficial to include all rooms on high-risk wards or throughout a facility in disinfection interventions? Fourth, should disinfection interventions strive to "get to zero" positive cultures after disinfection, or can similar results be obtained if contamination is reduced but not eliminated? Fifth, does adjunctive use of automated devices for terminal disinfection confer additional benefit over standard cleaning, particularly if measures are taken to optimize standard cleaning and disinfection? Finally, how can we integrate environmental disinfection with other control strategies to achieve optimal impact? For example, daily disinfection of surfaces combined with daily chlorhexidine bathing might provide more effective source control than either strategy alone. Efforts to efficiently and accurately identify patients who shed pathogens into the environment might enhance the impact of interventions by focusing cleaning efforts on the sites most likely to be contaminated.

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