INTRODUCTION

Understanding and Preventing Transmission of Healthcare-Associated Pathogens Due to the Contaminated Hospital Environment

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More than 20 years ago, Dr Robert Weinstein estimated that the source of pathogens causing a healthcare-associated infection in the intensive care unit was as follows: patients' endogenous flora, 40%–60%; cross infection via the hands of personnel, 20%–40%; antibiotic-driven changes in flora, 20%–25%; and other (including contamination of the environment), 20%.[1] Over the past decade, substantial scientific evidence has accumulated indicating that contamination of environmental surfaces in hospital rooms plays an important role in the transmission of several key healthcare-associated pathogens, including methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant *Enterococcus* (VRE), *Clostridium difficile*, *Acinetobacter*, and norovirus (Table 1).[2-6] All of these pathogens have been demonstrated to persist in the environment for hours to days (and, in some cases, months), to frequently contaminate the surface environment and medical equipment in the rooms of colonized or infected patients, to transiently colonize the hands of healthcare personnel (HCP), to be associated with person-to-person transmission via the hands of HCP, and to cause outbreaks in which environmental transmission was deemed to play a role. Furthermore, hospitalization in a room in which the previous patient had been colonized or infected with MRSA, VRE, *C. difficile*, multidrug-resistant *Acinetobacter*, or multidrug-resistant *Pseudomonas* has been shown to be a risk factor for colonization or infection with the same pathogen for the next patient admitted to the room.[7-10]

Although pathogen transfer from a colonized or infected patient to a susceptible patient most commonly occurs via the hands of HCP, contaminated hospital surfaces and medical equipment (and, less commonly, water and air) can be directly or indirectly involved in the transmission pathways. These transmission pathways and methods to interrupt transmission have been diagramed.[5,11] HCP have frequent contact with environmental surfaces in patients' rooms, providing ample opportunity for contamination of gloves and/or hands.[12] Importantly, hand contamination with MRSA has been demonstrated to occur with equal frequency when HCP have direct contact with a colonized or infected patient or through touching only contaminated surfaces.[13] The most important risk factor for HCP hand and glove contamination with multidrug-resistant pathogens has been demonstrated to be positive environmental cultures.[14]

To decrease the frequency and level of contamination of environmental surfaces and medical equipment in hospital rooms, routine and terminal disinfection with a germicide has been recommended.[15] Unfortunately, routine and terminal cleaning of room surfaces by environmental services personnel and medical equipment by nursing staff is frequently inadequate. Multiple studies have demonstrated that less than 50% of hospital room surfaces are adequately cleaned and disinfected when chemical germicides are used.[16,17] Similarly, inadequate cleaning of portable medical equipment by nursing staff has also been demonstrated.[18] The implementation of enhanced education, checklists, and methods to measure the effectiveness of room cleaning (eg, use of fluorescent dye) with immediate feedback to environmental services personnel has been found to improve cleaning and lead to a reduction in healthcare-associated infections.[19] No-touch methods (eg, ultraviolet C [UV-C] light and hydrogen peroxide systems) have been developed to improve terminal room disinfection.[20] UV-C light has been demonstrated to decrease the level of *C. difficile* spores on contaminated surfaces in patient rooms,[21] while hydrogen peroxide systems used in rooms of patients colonized or infected with a multidrug-resistant organism has been shown to decrease the risk of a subsequent patient admitted to the room developing infection or colonization with any multidrug-resistant organism.[22]

This special issue of *Infection Control and Hospital Epidemiology* is focused on the epidemiology and prevention of healthcare-associated infections associated with the hospital environment and includes 21 papers. Although space precludes describing each individual paper here, this issue details

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TABLE 1. Evidence Supporting the Role of the Contaminated Surface Environment in the Transmission of Several Key Healthcare-Associated Pathogens

The surface environment in rooms of colonized or infected patients is frequently contaminated with the pathogen
The pathogen is capable of surviving on hospital room surfaces and medical equipment for a prolonged period of time
Contact with hospital room surfaces or medical equipment by healthcare personnel frequently leads to contamination of hands and/or gloves
The frequency with which room surfaces are contaminated correlates with the frequency of hand and/or glove contamination of healthcare personnel
Clonal outbreaks of pathogens contaminating the room surfaces of colonized or infected patients are demonstrated to be due to person-to-person transmission or shared medical equipment
The patient admitted to a room previously occupied by a patient colonized or infected with a pathogen (eg, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant *Enterococcus*, *Clostridium difficile*, and *Acinetobacter*) has an increased likelihood of developing colonization or infection with that pathogen
Improved terminal cleaning of rooms leads to a decreased rate of infections
Improved terminal disinfection (eg, with vaporized hydrogen peroxide) leads to a decreased rate of infection in patients subsequently admitted to the room in which the prior occupant was colonized or infected

the remarkable progress that has been made in understanding the role the contaminated hospital environment plays in transmission of healthcare-associated pathogens and potential control methods.

The frequency of contamination of room surfaces with aerobic gram-negative bacilli has been less studied than contamination due to MRSA, VRE, and *C. difficile*. After optimization of laboratory techniques, Judge et al[23] in a small study (ie, 6 room sites and 3 extended-spectrum β-lactamase [ESBL]–positive patients) found 4 of 18 surface sites in one patient's room to be positive for ESBL-producing *Klebsiella pneumoniae*. In a prospective study, Ajao et al[24] report that a prior room occupant's ESBL status was not significantly associated with acquisition of an ESBL-producing organism, although 6 (18%) of 32 of patients subsequently admitted to the room acquired a bacterial strain that was the same as or closely related to a strain from the prior room occupant. Thus, the data suggest a less important role for contaminated environment in the transmission of ESBL-producing bacteria than for MRA, VRE, and *C. difficile*. In contrast, Munoz-Price et al[25] report a high frequency of environmental contamination in the rooms of patients colonized or infected with *Acinetobacter baumannii*, compared with *A. baumannii*–negative patients (ie, 39% rooms positive vs 10%).

The most commonly used germicides for surface and equipment disinfection in hospital rooms have been quaternary ammonium compounds and phenolics. Fertelli et al[26] report similar effectiveness for equipment disinfection using an electrochemically activated saline solution containing 0.05% hypochlorous acid. Boyce and Havill[27] report excellent effectiveness of an improved hydrogen peroxide wipe product for both surface and medical equipment disinfection.

This issue contains an excellent review of methods to improve environmental cleaning and disinfection by Carling and Huang.[28] In a small study, Guerrero et al[29] demonstrated that prior education and silent direct observation of environmental service workers resulted in significant improvements in environmental cleaning, as measured by a reduction in surfaces contaminated with *C. difficile* spores. In an excellent study, Sitzlar et al[30] demonstrated a dramatic reduction in the frequency of surface cultures positive for *C. difficile* by means of sequential cleaning and disinfection interventions (ie, monitoring of cleaning by fluorescent markers with feedback, use of a UV-C room disinfection device, and enhanced standard disinfection of *C. difficile* rooms that included a dedicated daily disinfection team).

As noted above, no-touch methods have been developed to improve terminal room disinfection. In this issue, Varma et al[31] report an approximately 1-$\log_{10}$ decrease in total aerobic colony-forming units (CFUs) using a handheld UV device, while Anderson et al[32] report a 1–2-$\log_{10}$ decrease in target pathogens (ie, *C. difficile*, *Acinetobacter*, and VRE) on room surfaces using a UV-C device designed for room decontamination. A major limitation of no-touch methods of terminal disinfection is the time required for room disinfection (shorter with UV devices than with those generating hydrogen peroxide). Rutala et al[33] report that using a nanostructured UV-reflective wall coating can significantly reduce the time needed to inactivate MRSA (from 25 to 5 minutes) and *C. difficile* (from 44 to 9 minutes). Whether to routinely discard packaged items stored in rooms of patients under contact precautions is unclear, but studies have demonstrated that they may become contaminated with pathogens. Otter et al[34] report that 7%–9% of supplies were contaminated with 1 or more multidrug-resistant pathogens and that hydrogen peroxide vapor room disinfection inactivated the multidrug-resistant pathogens on the packaging of all supplies in treated rooms.

Self-disinfecting surfaces are currently being assessed as a measure to reduce the bioburden of pathogens on room surfaces and prevent infection and colonization with healthcare-associated pathogens. Compared with no-touch methods, they have the advantage of continuously decreasing the bioburden and being able to be used throughout a patient's room occupancy. In this issue, Schmidt et al[35] show that copper bed rails reduced the bioburden on the rails by approximately

1–2-$\log_{10}$ CFUs and that, unlike standard disinfection, a reduced bioburden was maintained for hours after standard cleaning. In an important study using a randomized trial, Salgado et al[36] reported that the installation of multiple copper-coated surfaces in hospital rooms reduced the rate of healthcare-associated infections by more than 50%. A limitation of their study was the failure to assess the frequency of HCP hand hygiene and the effectiveness of routine and terminal room disinfection; an imbalance in each of these activities could have biased the study results.

This special issue demonstrates the rapid strides being made in understanding the role the contaminated environment plays in the transmission of several key healthcare-associated pathogens. More importantly, several articles demonstrate that enhanced cleaning, the use of no-touch methods for terminal room disinfection, and potentially the use of self-disinfecting surfaces may aid in reducing healthcare-associated infections. Finally, the commentary by Zimring et al[37] makes a plea for the evidence-based design of healthcare facilities.

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REFERENCES

1. Weinstein RA. Epidemiology and control of nosocomial infections in adult intensive care units. *Am J Med* 1991;91(suppl 3B): 179S–184S.
2. Boyce JM. Environmental contamination makes an important contribution to hospital infection. *J Hosp Infect* 2007;65(suppl 2):50–54.
3. Weber DJ, Rutala WA, Miller MB, Huslage K, Sickbert-Bennett E. Role of hospital surfaces in the transmission of emerging health care–associated pathogens: norovirus, *Clostridium difficile*, and *Acinetobacter* species. *Am J Infect Control* 2010;38(5 suppl 1):S25–S33.
4. Weber DJ, Rutala WA. The role of the environment in transmission of *Clostridium difficile* infection in healthcare facilities. *Infect Control Hosp Epidemiol* 2011;32:207–209.
5. Otter JA, Yezli S, French GL. The role played by contaminated surfaces in the transmission of nosocomial pathogens. *Infect Control Hosp Epidemiol* 2011;32:687–699.
6. Otter JA, Yezli S, Salkeld JAG, French GL. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. *Am J Infect Control* (forthcoming).
7. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006;166: 1945–1951.
8. Drees M, Snydman DR, Schmid CH, et al. Prior environmental contamination increases the risk of acquisition of vancomycin-resistant enterococci. *Clin Infect Dis* 2008;46:678–685.
9. Nseir S, Blazejewski C, Lubret R, Wallet F, Courcol R, Durocher A. Risk of acquiring multidrug-resistant gram-negative bacilli from prior room occupants in the intensive care unit. *Clin Microbiol Infect* 2011;17:1201–1208.
10. Shaughnessy MK, Micielli RL, DePestel DD, et al. Evaluation of hospital room assignment and acquisition of *Clostridium difficile* infection. *Infect Control Hosp Epidemiol* 2011;32:201–206.
11. Rutala WA, Weber DJ. Cleaning, disinfection, and sterilization. In: Carrico R, ed. *APIC Text of Infection Control and Epidemiology.* 3rd ed. Washington, DC: Association for Professionals in Infection Control and Epidemiology, 2009:21-1–21-18.
12. Huslage K, Rutala WA, Sickbert-Bennett E, Weber DJ. A quantitative approach to defining "high-touch" surfaces in hospitals. *Infect Control Hosp Epidemiol* 2010;31:850–853.
13. Stiefel U, Cadnum JL, Eckstein BC, Guerrero DM, Tima MA, Donskey CJ. Contamination of hands with methicillin-resistant *Staphylococcus aureus* after contact with environmental surfaces and after contact with the skin of colonized patients. *Infect Control Hosp Epidemiol* 2011;32:185–187.
14. Morgan DJ, Rogawski E, Thom KA, et al. Transfer of multidrug-resistant bacteria to healthcare workers' gloves and gowns after patient contact increases with environmental contamination. *Crit Care Med* 2012;40:1045–1051.
15. Rutala WA, Weber DJ; Healthcare Infection Control Practices Advisory Committee. *Guideline for Disinfection and Sterilization in Healthcare Facilities, 2008.* http://www.cdc.gov/hicpac/pubs.html. Accessed January 25, 2013.
16. Carling PC, Parry MF, von Beheren SM; Healthcare Environmental Hygiene Study Group. Identifying opportunities to enhance environmental cleaning in 23 acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29:1–7.
17. Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang SS. Impact of environmental cleaning intervention on the presence of methicillin-resistant *Staphylococcus aureus* and vancomycin-resistant enterococci on surfaces in intensive care unit rooms. *Infect Control Hosp Epidemiol* 2008;29:593–599.
18. Havill NL, Havill HL, Mangione E, Dumigan DG, Boyce JM. Cleanliness of portable medical equipment disinfected by nursing staff. *Am J Infect Control* 2011;39:602–604.
19. Donsky C. Does improving cleaning reduce healthcare-associated infections? *Am J Infect Control* (forthcoming).
20. Rutala WA, Weber DJ. Are room decontamination units needed to prevent transmission of environmental pathogens? *Infect Control Hosp Epidemiol* 2011;32:743–747.
21. Boyce JM, Havill JL, Moore BA. Terminal decontamination of patient rooms using an automated mobile UV light unit. *Infect Control Hosp Epidemiol* 2011;32:737–742.
22. Passaretti CL, Otter JA, Reich NG, et al. An evaluation of environmental decontamination with hydrogen peroxide vapor for reducing the risk of patient acquisition of multidrug-resistant organisms. *Clin Infect Dis* 2013;56:27–35.
23. Judge C, Galvin S, Burke L, Thomas T, Humphreys H, Fitzgerald-Hughes D. Search and you will find: detecting extended-spectrum β-lactamase–producing *Klebsiella pneumoniae* from a patient's immediate environment. *Infect Control Hosp Epidemiol* 2013;34:534–536.
24. Ajao AO, Johnson JK, Harris AD, et al. Risk of acquiring

extended-spectrum β-lactamase–producing *Klebsiella* species and *Escherichia coli* from prior room occupants in the intensive care unit. *Infect Control Hosp Epidemiol* 2013;34:453–458.
25. Munoz-Price LS, Namias N, Cleary T, et al. *Acinetobacter baumannii*: association between environmental contamination of patient rooms and occupant status. *Infect Control Hosp Epidemiol* 2013;34:517–520.
26. Fertelli D, Cadnum JL, Nerandzic MM, Sitzlar B, Kundrapu S, Donskey CJ. Effectiveness of an electrochemically activated saline solution for disinfection of hospital equipment. *Infect Control Hosp Epidemiol* 2013;34:543–544.
27. Boyce JM, Havill NL. Evaluation of a new hydrogen peroxide wipe disinfectant. *Infect Control Hosp Epidemiol* 2013;34:521–523.
28. Carling PC, Huang SS. Improving healthcare environmental cleaning and disinfection: current and evolving issues. *Infect Control Hosp Epidemiol* 2013;34:507–513.
29. Guerrero DM, Carling PC, Jury LA, Ponnada S, Nerandzic MM, Donskey CJ. Beyond the Hawthorne effect: reduction of *Clostridium difficile* environmental contamination through active intervention to improve cleaning practices. *Infect Control Hosp Epidemiol* 2013;34:524–526.
30. Sitzlar B, Deshpande A, Fertelli D, Kundrapu S, Sethi AK, Donskey CJ. An environmental disinfection odyssey: evaluation of sequential interventions to improve disinfection of *Clostridium difficile* isolation rooms. *Infect Control Hosp Epidemiol* 2013;34:459–465.
31. Varma G, Savard P, Coles C, et al. Hospital room sterilization using far-ultraviolet radiation: a pilot evaluation of the Sterilray device in an active hospital setting. *Infect Control Hosp Epidemiol* 2013;34:536–538.
32. Anderson DJ, Gergen MF, Smathers E, et al; CDC Prevention Epicenters Program. Decontamination of targeted pathogens from patient rooms using an automated ultraviolet-C-emitting device. *Infect Control Hosp Epidemiol* 2013;34:466–471.
33. Rutala WA, Gergen MF, Tande BM, Weber DJ. Rapid hospital room decontamination using ultraviolet (UV) light with a nanostructured UV-reflective wall coating. *Infect Control Hosp Epidemiol* 2013;34:527–529.
34. Otter JA, Nowakowski E, Salkeld JAG, et al. Saving costs through the decontamination of the packaging of unused medical supplies using hydrogen peroxide vapor. *Infect Control Hosp Epidemiol* 2013;34:472–478.
35. Schmidt MG, Attaway HH III, Fairey SE, Steed LL, Michels HT, Salgado CD. Copper continuously limits the concentration of bacteria resident on bed rails within the intensive care unit. *Infect Control Hosp Epidemiol* 2013;34:530–533.
36. Salgado CD, Sepkowitz KA, John JF, et al. Copper surfaces reduce the rate of healthcare-acquired infections in the intensive care unit. *Infect Control Hosp Epidemiol* 2013;34:479–486.
37. Zimring C, Denham ME, Jacob JT, et al. Evidence-based design of healthcare facilities: opportunities for research and practice in infection prevention. *Infect Control Hosp Epidemiol* 2013;34:514–516.