COMMENTARY

Improving Healthcare Environmental Cleaning and Disinfection: Current and Evolving Issues

Philip C. Carling, MD;[1] Susan S. Huang, MD, MPH[2]

Over the past several years, there has been a growing recognition that contamination of the patient environment by all bacterial and viral pathogens frequently associated with healthcare-associated infections (HAIs) occurs in wide range of healthcare settings.[1-3] In the past decade, increasing evidence has emerged to highlight lapses in procedures for and quality of healthcare cleaning and disinfection despite the presence of institutional policies consistent with national guidance. Visual assessment was seen as the gold standard for monitoring the quality of cleaning by environmental services (EVS) workers[4] until several studies consistently demonstrated that residual pathogens were present on patient care surfaces after routine cleaning[5-9] and that methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE) could be transmitted to patients from prior room occupants despite terminal cleaning with high-compliance visual inspection.[10-13] In addition, the presence of orphan items—mobile healthcare equipment where ownership of cleaning and disinfection is unclear, such as glucometers, intravenous poles, bar-coding scanners, and computers on wheels—highlights further vulnerabilities in adequate cleaning of patient care areas.[13-15] As summarized in Table 1, multiple studies have clarified key factors that define both our basic understanding of the transmission of healthcare-associated pathogens from environmental surfaces in patient care areas to susceptible patients and the challenges related to optimizing the adequacy of disinfection cleaning for infection prevention.[1-3,5,16-33]

As our understanding of the critical factors in environmental cleaning and disinfection improves (Table 1), it is important to assess the challenges found in our current approach to disinfection cleaning interventions and to identify necessary leading-edge research opportunities that will define best practices in environmental cleaning across the spectrum of healthcare settings.

CURRENT ISSUES IN HEALTHCARE ENVIRONMENTAL CLEANING AND DISINFECTION

Despite the many gains noted in Table 1, there remains a substantial need to better understand the clinical effectiveness and magnitude of infection prevention and patient reassurance derived from the current array of cleaning practices, various disinfectants and application methods, and evolving technological advances. We describe below important elements of environmental cleaning and disinfection and discuss evidence gaps for future research.

Policies

The Centers for Disease Control and Prevention's (CDC's) "Options for Evaluating Environmental Cleaning" guidance "encourages all hospitals to implement and to develop programs to optimize the thoroughness of high touch surface cleaning."[34] Hospitals are advised to first implement a program consisting of optimization of current policies and procedures related to environmental disinfection cleaning (level 1). Such institutional policies should include the use of an Environmental Protection Agency (EPA)–registered hospital-approved disinfectant in patient care areas in conjunction with a process for adequate training and regular retraining of all staff who have cleaning and disinfection responsibilities. These policies should also address ownership for cleaning and disinfection of mobile and orphan patient care equipment or a process by which ownership is determined and followed.

Practice

The 2010 CDC guidance further recommends that hospitals that have obtained a high compliance rate with surface cleaning move to a program involving a system for objective ongoing monitoring of cleaning practice in order to use such data in structured educational interventions within the institution (level 2). In recent years, substantial contributions

Affiliations: 1. Infectious Diseases Section, Carney Hospital and Boston University School of Medicine, Boston, Massachusetts; 2. Division of Infectious Diseases and Health Policy Research Institute, University of California, Irvine, School of Medicine, Irvine, California.

Received January 8, 2013; accepted January 11, 2013; electronically published April 9, 2013.

© 2013 by The Society for Healthcare Epidemiology of America. All rights reserved. 0899-823X/2013/3405-0010$15.00. DOI: 10.1086/670222

https://doi.org/10.1086/670222 Published online by Cambridge University Press

TABLE 1. Epidemiologic and Interventional Factors Related to Healthcare-Associated Pathogen Transmission from Environmental Surfaces

Recent evidence extending the case for the importance of environmental pathogens in healthcare-associated infections	Representative references and review articles
Healthcare-associated pathogens survive well on dry surfaces	1, 2, 15–18
Environmental surfaces are frequently contaminated with healthcare-associated pathogens; orphan items (mobile items often without clear cleaning ownership) need to be included in assessments of appropriate environmental cleaning	1, 2, 13–15, 19, 21, 22
Contamination from colonized patients may be similar to that from infected patients	23–25
Environmental surfaces frequently contaminate healthcare provider hands, and environmental pathogen strains have been linked to outbreaks	15, 23, 24, 29–31
Previously contaminated rooms increase transmission risk	10–12
Many patient areas are not cleaned according to policy	1, 20, 38
Improved thoroughness of disinfection cleaning decreases environmental contamination	23, 28, 32, 33
Disinfection cleaning can be programmatically improved	8, 9, 16, 19, 28, 35–37
Increasing breadth of environmental cleaning agents and methods (eg, bleach, quaternary ammonium, hydrogen peroxide, and ultraviolet light)	1, 2, 56, 69–72
Improved disinfection cleaning decreases acquisition of healthcare-associated pathogens	8, 27

have been made in attaining and maintaining high compliance by improving monitoring and feedback systems.[35-38] With evidence that visual inspection is insufficient to ensure adequate removal of important healthcare-associated pathogens, alternative methods have succeeded in improving the evaluation and quality of cleaning and disinfection. Specifically, more comprehensive risk-based audit checklists and ultraviolet (UV) light or bioluminenscence-based adenosine triphosphate (ATP) assays have been evaluated as routine monitoring systems.[39,40]

Evidence is greatest for the use of invisible UV markers whereby precleaning placement on high-touch surfaces by EVS workers or infection prevention monitors allows assessment of the EVS workers' success at removal during cleaning. Use of these markers has the advantage of being readily understandable by EVS workers, including the ability for direct and immediate feedback.[16] In addition, it has been associated with the reduction in important HAI pathogens on surfaces,[9,32,41] and although further research is needed in this regard, its use has been associated with reduced transmission of HAI pathogens.[42] Bioluminenscence-based ATP assays have also been evaluated for detection of residual organic material on postcleaning surfaces. They also have the advantage of direct and immediate feedback.[39,43] However, more evidence is needed to associate ATP levels with the presence of microbial pathogens and the reduction of transmission.[44-47]

Improved monitoring systems beyond visual inspection should be considered a necessity to ensure adequate quality of cleaning and disinfection. These systems should be jointly selected and supported by infection prevention and EVS leadership.[34] Since culturing of surfaces is expensive and generally limited to research settings, adoption of intensive checklists and/or objective monitoring systems is already warranted because of the inadequacies of visual monitoring and the need to demonstrate under the Joint Commission standard EC.04.01.03.EP2 that "results of data analysis [are used to] identify [and correct] opportunities to resolve environmental safety issues."[48] It is important that objective monitoring be a joint partnership between EVS and infection prevention, which is supported by the Centers for Medicare and Medicaid Services standard.[49] For example, it may be beneficial to have the monitoring program principally conducted by EVS supervisors where feedback is directly linked to an authority structure for praise and correction. However, like many self-observation processes, inherent bias exists and additional safeguards are necessary for internal and external validity. Thus, periodic external validation by infection prevention and retraining of the monitoring process may be critically important for ensuring adequate feedback and high compliance. This may be particularly important with the high turnover that often occurs in EVS programs. Additional information regarding the development of programs to monitor environmental cleaning thoroughness may be found in recent articles[16-50] and web-based materials.[51]

There also is a clear need for there to be a coordinated approach to jointly optimizing all basic infection prevention practices (eg, hand hygiene, compliance with contact precautions, and prevention bundles) and environmental hygiene practice. As an example, nearly all US hospitals are highly invested in hand hygiene optimization, whereas relatively few have partnered with EVS workers to implement objective monitoring and feedback (CDC level 2) programs to ensure optimal disinfection cleaning of rooms, common areas, and orphan items. Since focusing on one modality and not the others will blunt the impact of infection prevention strategies on pathogen transmission, there is a clear need to concomitantly optimize these essential prevention practices. Indeed, failure to simultaneously maintain high compliance across all these processes may limit the benefit of unimodal campaigns, as evidenced by the marginal clinical benefit of improved hand hygiene practice in well-resourced healthcare settings.[52-54]

https://doi.org/10.1086/670222 Published online by Cambridge University Press

Products and Technology

Beyond ensuring the quality and practice of cleaning, novel disinfectant agents and no-touch technological delivery systems have emerged and raised both questions and hopes for the future of cleaning and disinfection. These include but are not limited to hydrogen peroxide and paracetic acid cleaning agents as well as hydrogen peroxide vapor and UV-C decontamination units.

Advantages of accelerated hydrogen peroxide agents include their ideal safety and irritation profile among EPA-approved agents, being rated in the lowest EPA toxicity category for ingestion, inhalation, and skin hazard.[55] Evidence is just recently emerging on their comparative effectiveness for microbial disinfection.[56] In addition, UV-C is primarily being evaluated as a postdischarge terminal disinfection system for patient care rooms and raises the issue of human versus machine-based disinfection in light of broad variability in human performance[56-58] and the extensive efforts needed to corral and maintain the behavior necessary to maintain high disinfection standards. These UV-C units further highlight the power and potential of automation, with some ideally being able to sense, calibrate, target, and deliver the minimal dose for effective room disinfection by remote control. However, recommendations would be premature for the routine use of such novel technology, primarily because research on microbial effectiveness, cost-effectiveness, and pragmatic application is still under way.[56] Specific concerns for their use include the double-duty concerns that routine cleaning to remove dust and tidy the room are still needed. In addition, it is essential to remove spilled or caked-on liquid or solid material for touchless disinfection to be effective. Additional issues include the pragmatism of long application times of touchless technology, which range from 30 minutes to an hour for adequate microbial efficacy, although a recent study has demonstrated that the use of highly reflective paint may reduce UV-C application time to under 10 minutes for vegetative pathogens.[59] Finally, once practical application issues are addressed, cost-effectiveness analyses will be necessary given the current high cost of these technologies.

EVOLVING ISSUES

Improving Study Design

During the past 20 years, many published reports have described improved outcomes as the result of modifications in basic environmental cleaning. Unfortunately, causal analysis of essentially all of these studies has been greatly hampered by the simultaneous implementation of multiple interventions along with "improved cleaning." This issue is particularly well illustrated by the reports of interventions to minimize healthcare-onset *Clostridium difficile* infection beginning in the mid-1980s. Although more than 20 quasi-experimental, often-outbreak-associated studies have supported the likely effect of improved environmental hygiene on *C. difficile* transmission, all of these studies consist of several interventions implemented simultaneously. Because of known as well as additional unevaluated confounding variables in each study, it has been impossible to quantify the true impact of disinfection cleaning on *C. difficile* transmission.

Even when single environmental intervention cleaning agent change, for example, is pursued, published studies have not separated out the thoroughness of cleaning from the specific cleaning agent being tested. For example, it is possible that the novelty of a new cleaning agent results in better attention to process and increased thoroughness of cleaning that is behavioral in origin, due to the heightened attention surrounding change. This phenomenon has been suggested in other infection prevention activities.[60] To date, none of the clinical studies designed to assess specific disinfectant chemistries—particularly bleach—or application systems such as microfiber have controlled for this phenomenon by monitoring the thoroughness of general cleaning processes in addition to microbiological outcomes.[8,9,32,41] This will be important in future studies.

Furthermore, that many of these studies have been implemented in settings with transiently high rates of transmission of specific pathogens, such as *C. difficile*[61,62] and VRE,[63] limits the benefits attributed to any intervention. This is due to the statistical likelihood of regression to the mean following outlier rates.

There also is a need to substantially move environmental hygiene research from evaluation of practice to evaluation of objectively defined and reproducible clinically meaningful outcomes. While many studies have successfully introduced objective process measures for the thoroughness of disinfection cleaning practice and environmental contamination by clinically important bacterial pathogens, there is a need for large, well-conducted studies that use pathogen acquisition and clinical infection as outcomes to quantify the clinical impact of disinfection cleaning agents and thoroughness of practice. Such outcome studies, although logistically more complex and costly, provide critical validation of the value of improving routine disinfection cleaning practice. A few such studies of pathogen acquisition have been performed,[8,42] but larger, more generalizable ones are needed. For example, further investments can and should be made to conduct studies comparing the effectiveness of various cleaning protocols, practices, agents, and application systems on common healthcare-associated pathogens, such as MRSA, VRE, and *Acinetobacter*. Such clinical studies should compare new interventions to a standard of thorough, high-compliance, traditional disinfection cleaning based on objective monitoring to separate out process from the effectiveness of the agent or application system.

Fortunately, substantial improvement in HAI research related to choice of study design and analytics, as well as

https://doi.org/10.1086/670222 Published online by Cambridge University Press

TABLE 2. Critical Areas for Future Research

Topic	Purpose
Cost-effectiveness	Rigorous and unbiased cost-effectiveness analyses are needed to assess the value of new technological advances
Standardization	Studies to support standardized hospital use of a single Environmental Protection Agency–approved agent for cleaning and disinfection of common patient care items; potentially regulatory guidance for manufacturer testing of common cleaning agents to assess compatibility with product surfaces
Contact time	Studies to support regulatory guidance for testing of microbicidal activity using practical situations and surfaces common to healthcare settings
Threshold of environmental contamination below which acquisition of significant healthcare-associated pathogens effectively does not occur	Once an acceptable threshold is determined, it can be used as a gold standard for evaluating the ease by which various disinfectants and application methods achieve this threshold; this would obviate the need for multiple large clinical trials to demonstrate safety in preventing healthcare-associated infections for every new disinfectant or application method
Association of the threshold of environmental contamination and the infectious dose for key healthcare-associated pathogens	Making pragmatic recommendations that account for the likelihood that an infectious dose would be delivered from a contaminated environment through routine contact

research during nonoutbreak settings, has enabled some estimates of attributable risk due to environmental contamination and patient outcomes.[8,42] Studies using crossover and cluster-based designs, washout periods between interventions, and advanced evaluations addressing confounding and bias are beginning to provide a quality of research that is far beyond that seen just a few short years ago.[1,2,64,65] Well-designed comparative effectiveness trials are also being pursued.[66,67] Along with the need to optimize comparative effectiveness, translational research will be needed to quantify the relative clinical value of specific unimodal as well as programmatic interventions to decrease environmental pathogen transmission.[68] Finally, new genomic and polymerase chain reaction–based technologies may provide important insights into the role of the environment in healthcare-associated pathogen transmission.[69]

Additional Challenges

Beyond improved study design and analysis, there are several critical research needs in environmental cleaning and disinfection for healthcare facilities (Table 2).

During the past few years, innovative technologies have been developed that have the potential for providing enhanced environmental surface disinfection. As the economics of healthcare facilities markedly changes in response to accountable care structures, investing in such touchless environmental cleaning systems or making a business case for monitoring and objectively improving the thoroughness of basic disinfection will need to account for trade-offs between the cost of such investments and their ability to increase patient safety. Thus, it is even more imperative that estimates of attributable risk due to environmental contamination and attributable gains due to environmental interventions be pursued. Current monitoring programs (aggressive checklists, UV monitoring, and feedback) that improve the thoroughness of basic disinfection cleaning have shown limited (if any) increase in personnel costs,[35] since they are readily absorbed into current management systems that previously supported visual monitoring. Similarly, new disinfectants or cleaning cloths are generally limited to the change in product costs rather than additional personnel. Nevertheless, justifying the cost of novel technologies, which require new equipment and personnel resources, while there is still a need for personnel to perform basic cleaning will require more reliable estimates of attributable HAI disease reduction once logistical efficiencies are overcome. Future solutions that reduce personnel costs are conceptually possible, but their impact on the cost-effectiveness equation would require careful analysis.

Another important challenge involves addressing the fact that many manufacturers of healthcare items and equipment have widely varying recommendations for cleaning. This arises from the lack of clinically grounded standards for the testing of commonly used cleaning products and assessment of surface compatibility.[69-71] Thus, manufacturer recommendations for cleaning may be driven by the minimal requirements for commercialization or financial relationship to cleaning products, which then introduce bias in recommendations. Overall, the healthcare system cannot afford the cost, training, enforcement, and lack of standardization to follow a wide range of cleaning and disinfection recommendations for various items in a room or patient care area. Approaches are needed to define a standard that either accepts the hospital-approved method for general cleaning and disinfection or definitively demonstrates incompatibility rather than compatibility with common EPA-approved products.

Another critical area for research includes the need to influence regulation as related to contact time.[72] Currently, regulatory approval is based on efficacy of the product under conditions not reasonably found in healthcare settings. Approval of products for effectiveness under the conditions in

https://doi.org/10.1086/670222 Published online by Cambridge University Press

which they are intended is needed. While the rationale of going above and beyond what is needed may be appealing, the practical applications and costs of pursuing unnecessary rigor is detrimental to the economics and efficiency of health care without gaining any benefit to patient safety.

There also is a need to develop more globally applicable research models. Since the realistic goal of environmental cleaning and disinfection of patient care areas is not to produce a continuously sterile surface environment but rather to effectively decrease pathogen transmission, multicenter studies evaluating both environmental contamination and acquisition also have the potential for identifying a threshold of environmental contamination below which transmission—and therefore disease risk—is minimized. Identifying such a threshold for key healthcare-associated pathogens could then facilitate additional studies using such a threshold as an acceptable gold standard for minimizing disease risk. Such definitions would be particularly useful as the field struggles to understand the value of very high-cost disinfection technologies. In addition, such models could also be of value given the high cost of trials, since proof of disease reduction in a timely fashion would not be feasible for each and every advancement in cleaning policy practice or disinfection science.

CONCLUSIONS

In this commentary, we have discussed the significant advances in the science and practical application of environmental cleaning innovations, which have enabled broad new avenues for further research. In less than a decade, these advances have produced important gains in our conceptual thinking. These gains include shifts away from visual cleanliness and dust inspection to objective monitoring of cleaning thoroughness through UV and bioluminescent markers. It further includes improved study design that allows adequate controls and statistical power to detect the impact of the environment on acquisition and infection instead of microbiological contamination alone.

In this context, clear directions for the future have also emerged. These include the need to separate out the immense intersection between infection prevention processes that are rapidly and simultaneously being adopted in healthcare facilities to reduce environmental infectious risks as quickly as possible. Given the recent and notable innovation in automated cleaning modalities, there is a particularly pressing need to define their role in clinical practice by incorporating the principles of study design discussed above. In addition, the substantial cost of many innovations raises key questions about the attributable benefit and cost-effectiveness of such interventions during a time of ongoing reductions in healthcare reimbursement. We also highlight the need to separate out the process of cleaning from the agent itself when evaluating specific cleaning agents, since human factors have been identified as a vital and variable component of cleaning success. Furthermore, while it is universally understood that the goal of cleaning cannot be a sterile room, we remain ignorant about what level of contamination is operationally safe. Although identification of such thresholds in relation to clinical infection would require large research investments, they could provide a simple and durable gold standard that would impact all future studies in this field.

There is now the potential to develop clinically grounded studies to quantify what has been accepted as self-evident for more than 100 years, namely that healthcare disinfection cleaning practice is critically important to infection prevention. As we develop studies that are more rigorously designed, performed, and analyzed, we will be able to define and refine best-practice standards for disinfection cleaning.

ACKNOWLEDGMENTS

We dedicate this report to the memory of Judene Bartley, MS, MPH, CIC, whose insights and leadership related to environmental hygiene science greatly influenced this article.

Potential conflicts of interest. P.C.C. reports consulting with Ecolab and Steris and having a patent license with Ecolab. All other authors report no conflicts of interest relevant to this article. All authors submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest, and the conflicts that the editors consider relevant to this article are disclosed here.

Address correspondence to Philip C. Carling, MD, Department of Infectious Diseases, Carney Hospital, 2100 Dorchester Avenue, Boston, MA 02124 (pcarling@cchcs.org).

REFERENCES

1. Dancer SJ. Control of transmission of infection in hospitals requires more than clean hands. *Infect Control Hosp Epidemiol* 2010;31(9):958–960.
2. 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.
3. Dancer SJ. Hospital cleaning in the 21st century. *Eur J Clin Microbiol Infect Dis* 2011;30:1473–1481.
4. Dettenkofer M, Spencer RC. Importance of environmental decontamination—a critical view. *J Hosp Infect* 2007;65(suppl 2): 55–57.
5. Dancer SJ. How do we assess hospital cleaning? a proposal for microbiological standards for surface hygiene in hospitals. *J Hosp Infect* 2004;56:10–15.
6. Bhalla A, Pultz N, Gries D, et al. Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalized patients. *Infect Control Hosp Epidemiol* 2004; 25:164–167.
7. Hardy KJ, Oppeheim BA, Gossain S, Gao F, Hawkey PM. A study of the relationship between environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and patients' acquisition of MRSA. *Infect Control Hosp Epidemiol* 2006; 27:127–132.
8. Hayden MK, Bonten MJ, Blom DW, Lyle EA, van de Vijver DA, Weinstein RA. Reduction in acquisition of vancomycin-resistant *Enterococcus* after enforcement of routine environmental cleaning measures. *Clin Infect Dis* 2006;42(11):1552–1560.
9. Goodman ER, Platt R, Bass R, Onderdonk AB, Yokoe DS, Huang

https://doi.org/10.1086/670222 Published online by Cambridge University Press

SS. Impact of an 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(7):593–599.
10. Huang S, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. *Arch Intern Med* 2006;166: 1945–1951.
11. Drees M, Sneidman DR, Schmid CH, et al. Prior environmental contamination increases the risk of acquisition of vancomycin-resistant enterococci. *Clin Infect Dis* 2008;466:78–85.
12. 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(3):201–206.
13. Neely A, Maley MP, Warden GD. Computer keyboards as a reservoir for *Acinetobacter baumannii* in a burn hospital. *Clin Infect Dis* 1999;29:1358–1359.
14. Po JL, Burke R, Sulis C, Carling PC. Dangerous cows: an analysis of disinfection cleaning of computer keyboards on wheels. *Am J Infect Control* 2009;37:778–780.
15. Dumford DM 3rd, Nerandzic MM, Eckstein BC, Donskey CJ. What is on that keyboard? detecting hidden environmental reservoirs of *Clostridium difficile* during an outbreak associated with North American pulsed-field gel electrophoresis type 1 strains. *Am J Infect Control* 2009;37(1):15–19.
16. Carling PC, Bartley JM. Evaluating hygienic cleaning in healthcare settings: what you do not know can harm your patients. *Am J Infect Control* 2010;38(5 suppl 1):S41–S50.
17. Rutala WA, Webber D. Disinfection and sterilization: an overview. *Am J Infect Control* 2013 (forthcoming).
18. Otter JA. 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* 2013 (forthcoming).
19. Donskey CL. Does improving surface cleaning and disinfection reduce healthcare-associated infections? *Am J Infect Control* 2013 (forthcoming).
20. Carling PC. Methods for assessing the adequacy of practices and improving room disinfection. *Am J Infect Control* 2013 (forthcoming).
21. Webber D. Role of the environment in the transmission of *Clostridium difficile* in healthcare facilities. *Am J Infect Control* 2013 (forthcoming).
22. Aygün G, Demirkiran O, Utku T, et al. Environmental contamination during a carbapenem-resistant *Acinetobacter baumannii* outbreak in an intensive care unit. *J Hosp Infect* 2002;52(4):259–262.
23. Hayden MK, Blom DW, Lyle EA, Moore CG, Weinstein RA. Risk of hand or glove contamination after contact with patients colonized with vancomycin-resistant *Enterococcus* or the colonized patients' environment. *Infect Control Hosp Epidemiol* 2008; 29(2):149–154.
24. Boyce JM, Potter-Bynoe G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. *Infect Control Hosp Epidemiol* 1997;18(9):622–627.
25. Chang S, Sethi AK, Eckstein BC, Stiefel U, Cadnum JL, Donskey CJ. Skin and environmental contamination with methicillin-resistant *Staphylococcus aureus* among carriers identified clinically versus through active surveillance. *Clin Infect Dis* 2009; 48(10):1423–1428.
26. Riggs MM, Sethi AK, Zabarsky TF, Eckstein EC, Jump RL, Donskey CJ. Asymptomatic carriers are a potential source for transmission of epidemic and nonepidemic *Clostridium difficile* strains among long-term care facility residents. *Clin Infect Dis* 2007;45(8):992–998.
27. Dancer SJ. Importance of the environment in meticillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning. *Lancet Infect Dis* 2008;8(2):101–113.
28. Falk PS, Winnike J, Woodmansee C, Desai M, Mayhall CG. Outbreak of vancomycin-resistant enterococci in a burn unit. *Infect Control Hosp Epidemiol* 2000;21(9):575–582.
29. Bloemendaal AL, Fluit AC, Jansen WM, et al. Acquisition and cross-transmission of *Staphylococcus aureus* in European intensive care units. *Infect Control Hosp Epidemiol* 2009;30(2):117–124.
30. Rampling A, Wiseman S, Davis L, et al. Evidence that hospital hygiene is important in the control of methicillin-resistant *Staphylococcus aureus*. *J Hosp Infect* 2001;49(2):109–116.
31. Eckstein BC, Adams DA, Eckstein EC. Reduction of *Clostridium difficile* and vancomycin-resistant *Enterococcus* contamination of environmental surfaces after an intervention to improve cleaning methods. *BMC Infect Dis* 2007;7:61.
32. 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(5):524–526 (in this issue).
33. Carling PC. Assessing and improving the adequacy of terminal room cleaning and disinfection. Presented at: 5th Decennial International Conference on Healthcare-Associated Infections; March 18–22, 2010; Atlanta, GA.
34. Guh A, Carling P; for the Environmental Evaluation Workgroup. Options for evaluating environmental cleaning. Centers for Disease Control and Prevention website. http://www.cdc.gov/HAI/toolkits/Evaluating-Environmental-Cleaning.html. Published December 2010. Accessed September 20, 2012.
35. Carling PC, Parry MM, Rupp ME, Po JL, Dick B, Von Beheren S. Improving cleaning of the environment surrounding patients in 36 acute care hospitals. *Infect Control Hosp Epidemiol* 2008; 29(11):1035–1041.
36. Carling PC. Improving environmental hygiene in Iowa hospitals: will it make a difference? Presented at: 36th Iowa Infection Prevention and Control Seminar; May 2, 2012; Cedar Rapids, IA.
37. Murphy ML, Macbeth DA, Derrington P, Carling P. An assessment of high touch object cleaning thoroughness using a fluorescent marker in two Australian hospitals. *Healthc Infect* 2012; 16(4):156–163.
38. Carling PC, Po JL, Bartley J, Herwaldt L; Healthcare Environmental Hygiene Group. Identifying opportunities to improve environmental hygiene in multiple healthcare settings. Abstract presented at: 5th Decennial International Conference on Healthcare-Associated Infections; March 18–22, 2010; Atlanta, GA.
39. Boyce JM, Havill NL, Lipka A, Havill H, Rizvani R. Variations in hospital daily cleaning practices. *Infect Control Hosp Epidemiol* 2010;31(1):99–101.
40. Boyce JM, Havill NL, Havill HL, Mangione E, Dumigan DG, Moore BA. Comparison of fluorescent marker systems with 2 quantitative methods of assessing terminal cleaning practices. *Infect Control Hosp Epidemiol* 2011;32:1187–1193.
41. Munoz-Price LS, Bimbach DJ, Lubarsky DA, et al. Decreasing operating room environmental pathogen contamination

https://doi.org/10.1086/670222 Published online by Cambridge University Press

through improved cleaning practice. *Infect Control Hosp Epidemiol* 2012;33(9):897–904.
42. Datta R, Platt R, Yokoe DS, Huang SS. Environmental cleaning intervention and risk of acquiring multidrug-resistant organisms from prior room occupants. *Arch Intern Med* 2011;171(6): 491–494.
43. Department of Health. *Evaluation of ATP Bioluminesce Swabbing as a Monitoring and Training Tool for Effective Hospital Cleaning.* London: Department of Health, 2007. http://publications.spaceforhealth.nhs.uk/stream.php?id=3rZqqw12V8p3576s439pq78n29n7123o88q6. Accessed December 31, 2012.
44. Mulvey D, Redding P, Robertson C, et al. Finding a benchmark for monitoring hospital cleanliness. *J Hosp Infect* 2011;77(1): 25–30.
45. Whiteley GS, Derry C, Glasbey T. The comparative performance of three brands of portable ATP-bioluminometer intended for use in hospital infection control. *Healthc Infect* 2012;17(3):91–97.
46. Malik DJ, Shama G. Estimating surface contamination by means of ATP determinations: 20 pence short of a pound. *J Hosp Infect* 2012;80(4):354–355.
47. Shama G, Malik DJ. The uses and abuses of rapid bioluminescence-based ATP assays. *Int J Hyg Environ Health* 2013; 216(2):115–125.
48. Joint Commission Standards 2010. http://www.jointcommission.org/Standards/. Accessed December 31, 2012.
49. Centers for Medicare and Medicaid. *State Operations Manual: Appendix A—Survey Protocol, Regulations and Interpretive Guidelines for Hospitals.* http://www.cms.gov/Regulations-and-Guidance/Guidance/Manuals/downloads/som107ap_a_hospitals.pdf. Accessed September 18, 2012.
50. Yokoe DS, Mermel LA, Anderson DJ, et al. A compendium of strategies to prevent healthcare-associated infections in acute care hospitals. *Infect Control Hosp Epidemiol* 2008;29(suppl 1): S12–S21.
51. Association of Practitioners of Infection Control website. http://webinars.apic.org/webcast/login.php?ft=s&id=6438. Accessed December 31, 2012.
52. Rupp ME. Environmental cleaning and disinfection: only one piece of the critical care infection control puzzle. *Crit Care Med* 2011;39:881–882.
53. Carling PC, Polk RE. Optimize infection control using antimicrobial stewardship. *APUA Newsl* 2011;29(3):1–3.
54. Sepkowitz KA. Why doesn't hand hygiene work better? *Lancet Infect Dis* 2012;12:96–97.
55. Omidbakhsh N, Sattar SA. Broad-spectrum microbicidal activity, toxicologic assessment, and materials compatibility of a new generation of accelerated hydrogen peroxide–based environmental surface disinfectant. *Am J Infect Control* 2006;34:251–257.
56. Rutala WA. Research and new technologies in disinfection, sterilization and antisepsis. *Am J Infect Control* 2013 (forthcoming).
57. Matlow AG, Wray R, Richardson SE. Attitudes and beliefs, not just knowledge, influence the effectiveness of environmental cleaning by environmental service workers. *Am J Infect Control* 2012;40(3):260–262.
58. Rupp ME, Adler A, Schellen M, et al. The time spent cleaning a hospital room does not correlate with the thoroughness of cleaning. *Infect Control Hosp Epidemiol* 2013;34(1):100–102.
59. Rutala WA. *Safer Healthcare Environments for Infection Prevention.* University of North Carolina. http://www.unc.edu/depts/spice/dis/SaferEnvirIDWeek12.pdf. Accessed January 7, 2013.
60. Nijssen S, Bonten MJ, Weinstein RA. Are active microbiological surveillance and subsequent isolation needed to prevent the spread of methicillin-resistant *Staphylococcus aureus*? *Clin Infect Dis* 2005;40(3):405–409.
61. Wilcox MH, Fawley WN, Wigglesworth N, Parnell P, Verity P, Freeman J. Comparison of the effect of detergent vs. hypoclorite cleaning on environmental contamination in incidence of *Clostridium difficile* infection. *J Hosp Infect* 2003;54:109–114.
62. Orenstein R, Aronhalt KC, McManus JE Jr, Fedrew LA. A targeted strategy to wipe out *Clostridium difficile. Infect Control Hosp Epidemiol* 2011;32:1137–1139.
63. Grabsch EA, Mahony AA, Cameron DR. Significant reduction in vancomycin-resistant *Enterococcus* colonization and bacteremia after introduction of a bleach-based cleaning-disinfection programme. *J Hosp Infect* 2012;82:234–242.
64. Prencevich EN. Deconstructing the Veterans Affairs MRSA prevention bundle. *Clin Infect Dis* 2012;54:1621–1623.
65. Weinstein RA. The changing role of the healthcare epidemiologist: roles, future trends, non-infectious outcomes. Presented at: Society for Healthcare Epidemiology of America Spring Conference: Advancing Healthcare Epidemiology and Antimicrobial Stewardship; April 13–16, 2012; Jacksonville, FL.
66. Donskey CJ. An environmental disinfection to control *Clostridium difficile.* Agency for Healthcare Research and Quality. Grant R18 HS20004-01A1.
67. Anderson D. Novel strategies for enhanced terminal room disinfection. http://clinicaltrials.gov/ct2/show/NCT1579370?term=enhanced+terminal+room+disinfection&rank=1. Accessed January 7, 2013.
68. Po JL, Carling PC. The need for additional investigation of room decontamination processes. *Infect Control Hosp Epidemiol* 2010; 31:776–777.
69. Köser CU, Holden MT, Ellington MJ, et al. Rapid whole-genome sequencing for investigation of a neonatal MRSA outbreak. *N Engl J Med* 2012;366(24):2267–2275.
70. Sattar SA. Assessing the microbicidal activities of disinfectants and antiseptics: making label claims more relevant and reliable. In: Rutala WA, ed. *Disinfection, Sterilization, and Antisepsis: Principles, Practices, Current Issues, New Research, and New Technologies.* Washington, DC: Association of Practitioners in Infection Control, 2010.
71. Sattar SA. The crucial role of wiping in decontamination of high-touch environmental surfaces: review of current status and directions for the future. *Am J Infect Control* 2013 (forthcoming).
72. Rutala WA. Disinfection and sterilization: successes and Challenges. In: Rutala WA, ed. *Disinfection, Sterilization, and Antisepsis: Principles, Practices, Current Issues, New Research, and New Technologies.* Washington, DC: Association of Practitioners in Infection Control, 2010.

https://doi.org/10.1086/670222 Published online by Cambridge University Press