An evaluation of patient area cleaning in 3 hospitals using a novel targeting methodology

Philip C. Carling, MD,[a,d] Janet Briggs, BSN,[a] Deborah Hylander, BSN,[b] and Jeannette Perkins, BSN[c]
Boston, Quinccy, and Sandwich, Massachusetts

Background: Although environmental cleaning and disinfecting practices have become a cornerstone of patient care, assessment of actual compliance with such procedures has not been reported. Using a novel methodology, we developed a means to monitor directly such activities.

Methods: A nontoxic target solution, which intensely fluoresces with a black light, was formulated to be inconspicuous yet readily removed by housekeeping products. Small volumes of material were confidentially applied to 12 target sites in patient rooms in 3 hospitals following terminal cleaning. The targets were reevaluated following terminal cleaning after several patients had occupied the room.

Results: One hundred fifty-seven rooms and 1404 targets were evaluated. In the 3 hospitals studied, only 45%, 42%, and 56% of targets were removed by routine terminal cleaning/disinfecting activities. The frequency with which various individual sites were cleaned varied widely but was similar in all hospitals.

Conclusion: The use of a novel target compound to evaluate housekeeping practices confirmed high rates of cleaning of traditional sites but poor cleaning of many sites that have significant potential for harboring and transmitting microbial pathogens. This methodology has the potential for being used to evaluate objectively the cleaning/disinfecting activities in various health care settings. (Am J Infect Control 2006;34:513-9.)

During the past decade, controlling and limiting the spread of health care-associated pathogens has become one of the most challenging aspects of health care epidemiology.[1-3] Unfortunately, the continuing escalation of infections with these pathogens has led to more than 1.5 million people developing resistant hospital-acquired infections in the United States annually.[4] Although enhancement of hand hygiene through the development of user-friendly, alcohol-based hand cleansers has proven to be a major development in health care-associated infection prevention, optimizing the manner in which they are utilized[5] and achieving consistently high levels of compliance with their use remain as challenges.[6-8] Although screening-based isolation practices have been advocated to limit the transmission of methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant *Enterococcus* (VRE),[9,10] logistical issues and concerns about the practical application and cost-effectiveness of such practices continue to be debated.[3,11,12] Although it has been suggested that screening-based isolation practices have the potential for reproducing the impact such practices had on the frequency of MRSA resistance in several European countries,[10,13] recent reports showing that overall nosocomial infection rates have not improved concomitantly suggest that reliance on such practices may alter the epidemiology but not the incidence of health care-associated infections. Indeed the overall nosocomial infection rates in these northern European countries are currently quite similar to rates in southern European countries and US hospitals.[14] Despite appropriate isolation practices, outbreak persistence as well as significant environmental contamination has been documented with VRE[15-17] and MRSA[18] as well as with *Clostridium difficile*, for which screening is not feasible.[19] These programmatic as well as pathogen-based issues clearly have the potential for limiting the effectiveness of current as well as proposed isolation practices.[10,20]

In the context of such limitations, it has been suggested that enhancement of existing cleaning/disinfection practices deserves further consideration and evaluation.[20,21] Irrespective of the fact that it is not currently feasible to define independently the

From the Department of Hospital Epidemiology, Carney Hospital,[a] Boston; Infection Control Department, Quincy Medical Center,[b] Quincy; Infection Control Department, Rehabilitation Hospital of the Cape and Islands,[c] Sandwich; Boston University School of Medicine,[d] Boston.

Winner of the William A. Rutala Research Award and Blue Ribbon Abstract Award: 31st Annual Meeting of the Association for Professionals in Infection Control, Phoenix, Arizona, June 2004 (Abstract ID 12653).

Reprint requests: Philip C. Carling, Department of Hospital Epidemiology, Carney Hospital, 2100 Dorchester Avenue, Boston, MA 02124. E-mail: pcarling@cchcs.org.

0196-6553/$32.00

doi:10.1016/j.ajic.2005.09.001

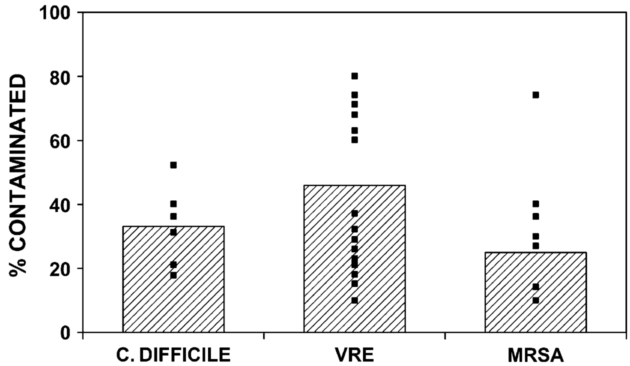

Fig 1. The proportion of environmental surface cultures positive for *C difficile*, VRE, and MRSA reported in the literature. Each point represents a separate study and the column, the mean for that pathogen.[26-47]

	VRE	MRSA	C. difficile
Bed Rails	+++++++	+	+++
Bed Table	++++++	+	
Door Knobs	++	++	+
Doors	+++	+	
Call Button	+++	+	++
Chair	++	+	++
Tray Table	+++	++	
Toilet Surface	+		++++
Sink Surface	+	+	+++
Bedpan Cleaner			+

Fig 2. The relative frequency with which surfaces in the near patient environment have been found to culture VRE, MRSA, and *C difficile*. Each + represents a single report in the literature.[19,21,26,27,30,31,33-36,39,40,42-44,46-49]

role of the hospital environment in the ongoing transmission of health care-associated pathogens, numerous studies over the past 20 years have confirmed the frequent contamination (Fig 1)[22-43] of many surfaces in the near patient environment (Fig 2)[15,17,22,23,26,27,29-32,35-37,39,40,42-45] with hospital-associated pathogens that are able to survive on inanimate surfaces for weeks to months.[46,47] With respect to individual pathogens, it has been found that high rates of environmental contamination with *C difficile* have been associated with both symptomatic[23,27,32] as well as asymptomatic[27] patients. Although documented by only a single study that evaluated the role of environmental contamination in the transmission of *C difficile* and found a strong correlation with the intensity of environmental contamination,[32] it is not surprising that outbreaks of *C difficile* infection have been successfully terminated by enhanced cleaning/disinfecting activities.[26,28,48-50] With respect to VRE, the role of environmental contamination in transmission was documented[51] and considered important prior to the promulgation of the 1995 Hospital Infection Control Practices Advisory Committee (HICPAC) guidelines to control the spread of VRE.[52] Recent studies have confirmed the frequency of VRE environmental contamination, which has been shown to be highly correlated with the number of body sites colonized[31] as well as the intensity of gastrointestinal tract colonization.[34] Furthermore, the ease with which gloved hands can become contaminated with VRE by limited contact with a colonized patient's bed rail and bedside table,[37] the rapid recontamination of surfaces in the near patient environment with VRE despite effective daily cleaning even in the absence of diarrhea,[39] and the occurrence of documented cases of direct transmission of VRE from the environment to patients[17,53,54] as well as the termination of a VRE outbreak in an intensive care unit (ICU) by enhanced cleaning activities[17] support the likely importance of the environment in the epidemiology of this pathogen.[39,55] Given the fact that MRSA is frequently found in the environment of both colonized and infected patients as well as colonized health care workers,[56] can be transmitted by the gloves of health care providers,[43] and has been shown to increase in concentration in the stool of colonized patients receiving broad spectrum antibiotics,[57] it is likely that environmental contamination plays a role in the spread of MRSA. In addition, DNA typing in 3 studies has supported the likely importance of environmental reservoirs in colonal MRSA and methicillin-susceptible *Staphylococcus aureus* (MSSA) outbreaks in hospitals lasting from 3 months to 5 years.[36,18,58]

These and similar observations have confirmed the long-standing belief that environmental cleaning/disinfecting activities are important in providing an optimally safe environment for patients and have led to the development of specific guidelines for environmental infection control in health care facilities. In 2002 the Centers for Disease Control and Prevention (CDC) recommended that hospitals "thoroughly clean and disinfect environmental medical equipment surfaces on a regular basis."[59] Similarly, the Society for Health Care Epidemiology of America's position paper regarding enhanced interventions to control the spread of resistant *Staphylococcus aureus* and enterococci recommended that hospitals "ensure" that their institutional methods of disinfecting surfaces be shown to be "adequate."[10] Also in 2003, the National Health Service of Great Britain specifically recommended that, "cleaning and disinfecting programmes and protocols for environmental surfaces in patient care areas would be defined."[14] Most recently, the draft guidelines for isolation precautions developed by the CDC emphasize the importance of environmental cleaning and disinfection activities.[60] Although these 4 guidelines specifically state that hospitals "ensure compliance by housekeeping staff with cleaning and disinfecting procedures,"[59] "ensure meticulousness of cleaning,"[10] "ensure high standards of cleanliness are being achieved,"[14] and "ensure consistent cleaning and disinfection of surfaces in close proximity to the patient and likely to be touched by the patient and health care worker,"[60] they provide no directives regarding the means by which hospitals are to assess their ability to comply with or "ensure" the effectiveness of such activities prospectively. In a similar manner, the Joint Commission for Health Care Accreditation 2004 standard states that hospitals are "expected to develop standards to measure staff and hospital performance in managing and improving the environment of care" without defining how to develop and objectively measure such standards.[61]

In view of the recognized importance of interventions to improve patient safety by minimizing the impact of ongoing contamination of "high touch" objects (HTOs)[59] with the resilient and pathogenic bacteria that frequently contaminate these surfaces and in the context of the above guidelines, we developed and tested a methodology to evaluate the thoroughness with which housekeeping activities were being carried out in our hospitals.

METHODS

Two of the hospitals involved in the study had similar demographics. They were both urban primary and secondary care institutions. Hospital A had 136 and hospital B had 115 medical/surgical beds with 15- and 14-bed combined medical/surgical ICUs, respectively. Although the hospitals had geographic proximity, their administrative, clinical, and housekeeping staffs were completely independent. Hospital C was a 60-bed, acute care, short-term rehabilitation hospital.

A targeting solution was developed using an environmentally stable nontoxic base to which was added a chemical marker that fluoresces brightly when exposed to black light. The material was developed to be inconspicuous, to dry rapidly on surfaces, to remain environmentally stable for several weeks, to resist dry abrasion, and to be easily removed with moisture accompanied by minimal abrasion. Small plastic squeeze bottles were used to dispense approximately 0.2 mL solution to standardized target sites. A group of 12 targets were chosen on the basis of the CDC's recommendation that enhanced cleaning activities should be directed at "high touch" surfaces,[59] as well as sites reported in the previously cited literature as being frequently contaminated with hospital-associated pathogens. Such surfaces included toilet handles, horizontal surface of toilet bowls, bedpan flushing devices, horizontal surface of sinks adjacent to a faucet, doorknobs (or push/grab plates), toilet area hand holds immediately adjacent to the toilet, bedside tables, telephone receivers, call buttons, overbed tables, seats of patient chairs, and frequently contacted areas on bedrails. To the degree possible, the targeting material was placed on the HTO in an area that was easily accessible to cleaning and in close proximity to that portion of the object most frequently contacted by patients' and health care workers' hands. HTOs were confidentially marked by one of the authors after a room had been terminally cleaned following discharge of its occupant. After 2 to 3 patients had occupied the room and the room was again terminally cleaned, a handheld black light was used to determine whether the marked HTOs in the room had been cleaned. Although the marking material was usually completely removed by routine disinfection cleaning, the object was considered cleaned if the target material was clearly disturbed. Patient room floors and room walls were not evaluated, given the limited potential for their serving as a source of transmission of nosocomial pathogens.[62] Statistical data analyses were performed using a 2-tailed Fisher exact test and were calculated with the use of Graph Pad (available at www.graphpad.com; GraphPad Inc., San Diego, CA).

RESULTS

During the study of periods ranging from 1 to 4 months, 60, 54, and 43 rooms were evaluated at the 3 hospitals. Overall, 47% of the 1404 HTOs evaluated were found to have been cleaned after several terminal cleanings, with the individual hospitals having cleaning rates of 45%, 42%, and 56% respectively. Although 12 separate targets were marked in many rooms, the absence of chairs or individual toilets in some rooms resulted in an average of 8.9 HTOs being assessed in the 157 rooms evaluated. As noted in Fig 3, high rates of cleaning, between 80% and 92%, were found for bedside tables, toilet tops, tray tables, and sinks. In contrast, several HTOs, including bedpan cleaning equipment, patient room, and bathroom doorknobs (or door pulls) as well as toilet handholds were cleaned in between 12.3% and 18% of rooms overall. The differences found between most often cleaned objects (>80%) and least often cleaned objects (<20%) in the 3 hospitals were highly significant ($P \leq .001$). The remaining objects, although more frequently cleaned

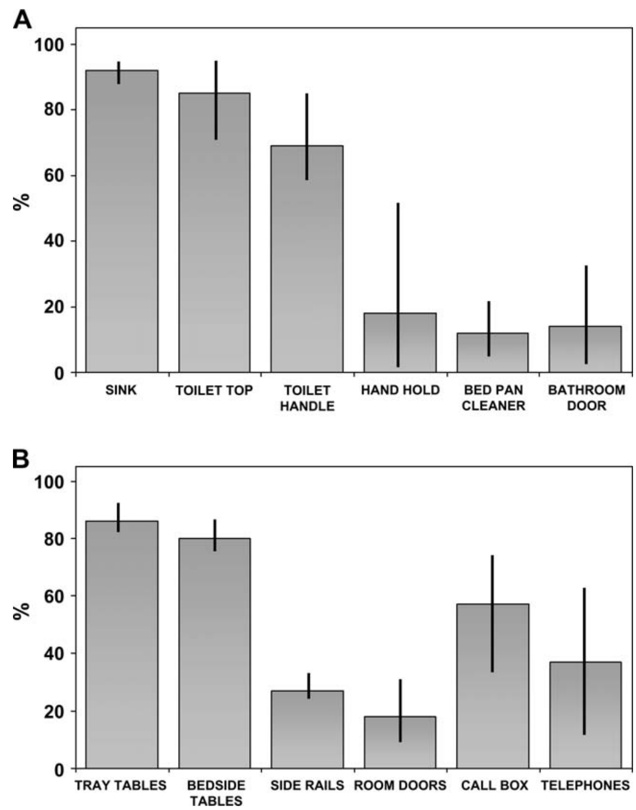

Fig 3. The proportion (%) of targets cleaned in (A) bathroom areas and (B) patient rooms. The columns represent the mean for the three hospitals. The vertical bars represent the range of cleaning observed.

than the group of least often cleaned objects, were, as a group, still significantly less frequently cleaned than the objects cleaned >80% of the time (mean, 88.3% vs 54.5%, respectively, $P \leq .001$).

DISCUSSION

The use of an environmentally stable, nontoxic, inconspicuous targeting solution allowed us to evaluate the thoroughness with which terminal cleaning was done at our three hospitals. Although the CDC 2003 Guidelines for Environmental Infection Control in Healthcare Facilities recommends "cleaning and disinfection of high touch surfaces (eg, doorknobs, bedrails, light switches in and around toilets in patients' rooms) on a more frequent schedule than minimal touch housekeeping services" (Environmental Services I, E, 3),[59] our results indicate that environmental services staff at the 3 hospitals we evaluated were not cleaning many of these HTOs as a regular part of terminal room cleaning. Given the consistently high frequency of cleaning documented for sinks, toilet tops, and tray tables, it would appear likely that the suboptimal cleaning of many HTOs such as bedpan cleaners, toilet area handholds, and doorknobs was due to a lack of appreciation for the potential role the latter objects have in the transmission of nosocomial pathogens rather than ineffective terminal disinfection cleaning in general. This possibility is further supported by the narrow range in the proportion of HTOs cleaned for the 2 most frequently cleaned objects (mean range, ±2.5%) among each of the 3 hospitals in contrast to the 4 least frequently cleaned objects (mean range, ±11.2%) as noted by the vertical bars in Fig 3. Although the limited size of this preliminary analysis precludes generalization of our results to other settings, it is particularly concerning that we consistently found the 2 least cleaned HTOs, namely bedpan cleaners (mean, 12.3%; range, 9%-20%) and toilet area handholds (mean, 17.7%; range, 0%-50%) represent objects with a high potential for contamination by environmentally resilient gastrointestinal colonizing pathogens such as *C difficile*; VRE; MRSA; and resistant, gram-negative bacilli. Given the effectiveness of disinfectants for a wide range of pathogens,[63,64] including antibiotic-resistant bacteria,[55,64-66] the fact that terminal cleaning/disinfection activities are not effective in substantially eliminating these pathogens from the near patient environment[41,20,44,55,67] suggests that the thoroughness of cleaning itself may be suboptimal if less than half of HTOs in these studies were actually cleaned as was the case in our institutions.

Although the documentation of suboptimal environmental cleaning of a range of HTOs in our hospitals may represent an isolated phenomenon, several reports suggest that suboptimal cleaning/disinfecting practices may be widespread. In 1998, Beyers et al reported finding 15.9% (range, 3%-32%) of 376 sampled sites still contaminated by VRE following routine cleaning.[20] Although the proportion of sites contaminated prior to evaluation was not assessed, the range of positive sites was similar to that reported in studies that evaluated contamination in rooms of patients with active VRE colonization or infection.[17,39,37] More recently, Bahalla et al found only a 50% decrease in surface contamination by several health care-associated pathogens immediately following routine cleaning and disinfection activities in 25 patient rooms.[40] Furthermore, several reports have shown insignificant differences in rates of environmental contamination in cleaned versus occupied rooms with MRSA[38] and VRE[40] as well as a group of several hospital-associated pathogens.[35] Finally, it is of note that several studies have clearly shown that enhanced cleaning significantly decreases environmental contamination with a range of health care-associated pathogens.[20,51,67,68] Taken together, these observations raise the possibility that institutional cleaning limitations in the thoroughness of disinfection cleaning may have an important role in the spread of health care-associated pathogens.

Only limited studies evaluating the thoroughness of environmental cleaning using an indirect methodology have been reported. An indirect evaluation of surface contamination with organic matter has been used in the food preparation industry.[44] This methodology, which employs a bioluminescence monitor to measure organic adenosine triphosphate (ATP) (found in all life forms except viruses) to detect the presence of organic material on surfaces, was used by Griffith et al to evaluate the effectiveness of surface cleaning/disinfection activities in an acute care hospital.[45] Although the authors found that the negative bioluminescence result correlated with low aerobic bacterial counts on surfaces, the fact that their testing was not able to distinguish between cleaned and noncleaned targets as well as the inability of the technology to exclude interference from nonbacterial-containing organic matter suggests that the high sensitivity of this methodology may limit its application in the general health care setting for the evaluation of environmental cleaning activities.[69] Although several recent studies have used environmental cultures to evaluate the effectiveness of disinfection/cleaning of contaminated patient rooms,[21,35,38,40] the cost and logistical complexity of such investigations has precluded their use in evaluating the overall effectiveness of institutional environmental services.[70,71]

Although it is generally accepted that such surface cleaning/disinfection of the near patient environment is an important component of institutional health care and in light of the substantial resources allocated to cleaning/disinfecting activities in health care facilities,[72] it is of note that the programatic effectiveness with which such activities are being carried out has not previously been evaluated prospectively over a several month period of time. To date, only 1 other study has evaluated the effectiveness and thoroughness of routine cleaning activities in hospitals. This report by Malek et al compared 2 standardized, observation-based audit guidelines[73,74] with a risk-based audit tool used in conjunction with rapid environmental testing with an ATP bioluminescence tool for several observation periods in 4 hospitals.[75] Although 90% of sites appeared visually clean immediately after routine disinfection/cleaning activities, none of the sites were found to be effectively cleaned using the ATP bioluminescence monitor, and only 10% met bacteriologic food-handling standards. Although the authors conclude that cleaning/disinfection activities were uniformly ineffective, it should be noted that objectively based standards for hospital cleaning have yet to be developed.

The primary limitation of our study relates to the fact that only 3 hospitals were evaluated, which precludes a broad generalization of the findings. Although we were unable to identify a basis for the similarity of results among the hospitals, the fact that they were within a 40-mile radius raises the possibility that these suboptimal overall cleaning rates may reflect a geographically localized phenomenon. In addition, our evaluation focused exclusively on the thoroughness with which terminal cleaning was being carried out. Given recent studies of the environmental epidemiology of VRE[33,37] and the limited effectiveness of daily cleaning activities[28,37,39] in contrast to terminal cleaning[29,39,61] on the prevalence of environmental contamination, it might have been useful to have undertaken an assessment of the thoroughness of both activities.

In light of these preliminary findings and in the context of the international concerns regarding the limitations of current interventions to improve patient safety by decreasing the ongoing transmission of health care-associated pathogens,[71,76] it may be important to evaluate further the role of optimized environmental cleaning/disinfection of the near patient environment to address more completely these problems. Given our observation that the most complete cleaning related to objects that are easily accessible and are commonly cleaned in the domestic environment as well as the consistency with which less traditional and more epidemiologically important objects were substantially less frequently cleaned, we believe that a similar analysis of the thoroughness of cleaning of the near patient environment in other health care facilities is warranted.

References

1. Weinstein R. Controlling antimicrobial resistance in hospitals: infection control and use of antibiotics. Emerg Infect Dis 2001;7:188-92.
2. Gerberding J. Hospital-onset infections: a patient safety Issue. Ann Intern Med 2002;137:665-70.
3. Boyce J, Havill N, Kohan C. Do infection control measures work for Methicillin-resistant *Staphylococcus aureus*? Infect Control Hosp Epidemiol 2004;25:395-401.
4. Infectious Diseases Society of America. Bad bugs, no drugs. Available from: http://www.idsociety.org. Accessed December 20, 2004.
5. Widmer A, Dangel M. Alcohol-based handrub: evaluation of technique and microbiological efficacy with international infection control professionals. Infect Control Hosp Epidemiol 2004;25:207-9.
6. Kim P, Roghmann M, Perencevich E, Harris A. Rates of hand disinfection associated with glove use, patient isolation and changes between exposure to various body sites. Am J Infect Control 2003;31:97-103.
7. Pyrek K. Infection prevention through propper hand hygiene and gloving. Infect Control Today 2004;7:44-7.
8. Kampf G, Kramer A. Epidemiologic background of hand hygiene and evaluation of the most important agents for scrubs and rubs. Clin Microbial Rev 2004;17:863-93.
9. Farr B, Sallgado C, Karchmer T, Sheretz R. Can antibiotic-resistant nosocomial infections be controlled? Lancet Infect Dis 2001;1:38-45.

10. Muto C, Jernigan J, Ostrowsky B, Richet M, Jarvis W, Boyce J. SHEA Guideline for preventing nosocomial transmission of multidrug-resistant strains of *Staphylococcus aureus* and Enterococcus. Infect Control Hosp Epidemiol 2003;24:362-86.
11. Jackson M, Jarvis W, Scheckler W. HHICPAC/SHEA-conflicting guidelines: what is the standard of care? Am J Infect Control 2004;32: 504-11.
12. Nijssen S, Bonten J, Weinstein R. Are active microbiological surveillance and subsequent isolation needed to prevent the spread of methicillin-resistant *Staphylococcus aureus*? Clin Infect Dis 2005;40: 405-9.
13. Tiemersma E, Bronzwaer S, Lyytikainen O, Degener J, Schrijnemakers P, Bruinsma N. Methicillin-resistant *Staphylococcus aureus* in Europe, 1999-2002. Emerg Infect Dis 2004;10:1627-34.
14. Department of Health. Winning ways. Working together to reduce healthcare associated infection in England: report from the Chief Medical Officer, London: Crown Copyright; 2003 (cited April 21, 2004). Available from: http://www.publications.doh.gov.uk/cmo/hai/winningways.pdf. Accessed February 11, 2005.
15. Boyce J, Mermel L, Zervos M, Rice L, Potter-Bynoe G. Controlling vancomycin-resistant enterococci. Infect Control Hosp Epidemiol 1995;16:634-7.
16. Lai K, Kelley A, Melvin Zita S, Belliveau P, Fontecchio S. Failure to eradicate vancomycin-resistant Enterococci in a university hospital and the cost of barrier precautions. Infect Control Hosp Epidemiol 1998;19:647-52.
17. Falk P, Winnike J, Woodmansee C, Desai M, Mayhall G. Outbreak of vancomycin-resistant Enterococci in a burn unit. Infect Control Hosp Epidemiol 2000;21:575-82.
18. Dominguez M, Lencastre H, Linares J, Tomasz T. Spread and maintenance of a dominant methicillin-resistant *Staphylococcus aureus* (MRSA) clone during an outbreak of MRSA disease in a Spanish hospital. J Clin Microbiol 1994;32:2081-7.
19. Nath S, Thornley J, Kelly M, Kucera B, On S. A sustained outbreak of *Clostridium difficile* in a general hospital: persistence of a toxigenic clone in four units. Infect Control Hosp Epidemiol 1994;15:382-9.
20. Byers K, Durbin L, Simonton B, Anglim A, Adal K, Farr B. Disinfection of hospital rooms contaminated with vancomycin-resistant *Enterococcus faecium*. Infect Control Hosp Epidemiol 1998;19:261-4.
21. Rutala W, Weber D. Infection control: the role of disinfection and sterilization. J Hosp Infect 1999;43(Suppl):43-55.
22. Fekety R, Kyung-Hee K, Brown D, Battis D, Cudmore M, Silva J. Epidemiology of antibiotic-associated colitis: isolation of *Clostridium difficile* from the hospital environment. Am J Med 1981;70:906-8.
23. Kim K, Fekety R, Batts D, Brown D, Cudmore M, Silva J. Isolation of *Clostirdium difficile* from the environment and contacts of patients with antibiotic-associated colitis. J Infect Dis 1981;143:42-50.
24. Rutala W, Katz E, Sherertz, Sarubbi F. Environmental study of a methicillin-resistant *Staphylococcus aureus* epidemic in a burn unit. J Clin Microbiol 1983;18:683-8.
25. Ansari S, Sattar S, Springthorpe V, Wells G, Tostowaryk W. Rotavirus survival on hands and transfer of infectious virus to animate and nonporous inanimate surfaces. J Clin Microbiol 1988;26:1513-8.
26. Kaatz G, Gitlin S, Schaberg D, Wilson K, Kauffman C, Seo S. Acquisition of *Clostridium difficile* from the hospital environment. Am J Epidemiol 1988;127:1289-93.
27. McFarland L, Mulligan M, Kwok R, Stamm W. Nosocomial acquisition of *Clostridium difficile* infection. N Eng J Med 1989;320:204-10.
28. Struellens M, Maas A, Nonhoff C, Deplano A, Rost F, Serruys E. Control of nosocomial transmission of *Clostridium difficile* based on sporadic case surveillance. Am J Med 1991;91(Suppl 3B):S138-43.
29. Boyce J, Opal S, Chow J, Zervos M, Potter-Bynoe G, Sherman B. Outbreak of multidrug-resistant *Enterococcus faecium* with transferable vanB class vancomycin resistance. J Clin Microbiol 1994;32:1148-53.
30. Shay D, Maloney S, Montecalvo M, Banerjee S, Wormser G, Arduino M. Epidemiology and mortality risk of vancomycin-resistant enterococcal bloodstream infections. J Infect Dis 1995;172:993-1000.
31. Bonten M, Hayden M, Nathan C, va Voorhis J, Matushek M, Slaughter S. Epidemiology of colonization of patients and environment with vancomycin-resistant enterococci. Lancet 1996;348:1615-9.
32. Samore M, Venkataraman L, DeGirolami P, Arbeit R, Karchmer A. Clinical and molecular epidemiology of sporadic and clustered cases of nosocomial *Clostridium difficile* Diarrhea. Am J Med 1996;100:32-40.
33. Lai K, Kelly A, Melvin Z, Belliveau P, Fontecchio S. Failure to irradicate vancomycin-resistant enterococci in a university hospital and the cost of barrier precautions. Infect Control Hosp Epidemiol 1998;19:647-52.
34. Donskey C, Chowdhry T, Hecker M, Hoyen C, Hanrahan J, Hujer A. Effect of antibiotic therapy on the density of vancomycin-resistant enterococci in the stool of colonized patients. N Eng J Med 2000;343: 1925-32.
35. Bures S, Fishbain J, Uyehara C, Parker J, Berg B. Computer keyboards, boards and faucet handles as reservoirs of nosocomial pathogens in the intensive care unit. Am J Infect Control 2000;28:465-70.
36. Rampling A, Wiseman S, Davis L, Hyett A, Walbridge A, Payne G. Evidence that hospital hygiene is important in the control of methicillin-resistant *Staphylococcus aureus*. J Hosp Infect 2001;49:109-16.
37. Ray A, Hoyen C, Taub T, Eckstein E, Donskey C. Nosocomial transmission of vancomycin-resistant enterococci from surfaces. JAMA 2002;287:1400-1.
38. Oie S, Hosokawa H, Kamiya A. Contamination of room door handles by methicillin-sensitive/methicillin-resistant *Staphylococcus aureus*. J Hosp Infect 2002;51:140-3.
39. Mayer R, Geha R, Helfand M, Hoyen C, Salata R, Donskey C. Role of fecal incontinence in contamination of the environment with vancomycin-resistant enterococci. Am J Infect Control 2003;31:221-5.
40. Bhalla A, Pultz N, Gries D, Ray A, Eckstein E, Aron D. Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalized patients. Infect Control Hosp Epidemiol 2004; 25:164-7.
41. Lemmen S, Hafner H, Zolldann D, Stanzel S, Lutticken R. Distribution of multi-resistant gram-negative versus gram-positive bacteria in the hospital inanimate environment. J Hosp Infect 2004;56:191-7.
42. Christiansen K, Tibbett P, Beresford W, Pearman J, Lee R, Coombs G, et al. Irradication of a large outbreak of a single strain of van B vancomycin-resistant enterococcus faecium at a major Australian teaching hospital. Infect Control Hosp Epidemiol 2004;25:384-90.
43. French G, Otter K, Shannon P. Survival of nosocomial bacteria dried in air and killing by hydrogen peroxide vapour. Abstracts of the 44th Interscience Conference on Antimicrobial Agents and Chemotherapy (abstr K-1602). Washington, DC; 2004. p. 376.
44. Davidson C, Griffith C, Peters C, Fielding L. Evaluation of two methods for monitoring surface cleanliness–ATP bioluminescence and traditional hygiene swabbing. Luminescence 1999;14:33-8.
45. Griffith C, Cooper R, Gilmore J, Davies C, Lewis M. An evaluation of hospital cleaning regimes and standards. J Hosp Infect 2000;45:19-28.
46. Clarke P, Humphreys H. Persistence of vancomycin-resistant enterococci (VRE) and other bacteria in the environment. Irish Med J 2001; 94:277-8. Available from: http://www.imj.iel. Accessed February 11, 2005.
47. French G, Otter J, Shannon K, Adams N, Watling D, Parks M. Tackling contamination of the hospital environment by methicillin-resistant *Staphylococcus aureus* (MRSA): a comparison between conventional terminal cleaning and hydrogen peroxide vapour decontamination. J Hosp Infect 2004;57:31-7.
48. Mayfield J, Leet T, Miller J, Mundy L. Environmental control to reduce transmission of *Clostridium difficile*. Clin Infect Dis 2000;31:995-1000.
49. Apisarnthanarak A, Zack J, Mayfield J, Freeman J, Dunne W, Little J, et al. Effectiveness of environmental and infection control programs to reduce transmission of *Clostridium difficile*. Clin Infect Dis 2004;39:601-2.

50. Hoffman P, Hawkins P, Phillips H, Reinhart T, Fletcher R, Moore N. Environmental management services project enhances infection control program. Abstracts of the Association for Practitioners in Infection Control Educational Conference and International Meeting (abstr 22353). Phoenix, AZ; 2004.
51. Livornese L, Dias S, Samel C. Hospital-acquired infection with vancomycin-resistant *Enterococcus faecium* transmitted by electronic thermometers. Ann Intern Med 1992;117:112-6.
52. Centers for Disease Control and Prevention. Recommendations for preventing the spread of vancomycin resistance: recommendations of the Hospital Infection Control Practices Advisory Committee (HICPAC). MMWR 1995;44:1-13.
53. Gould F, Freeman R. Nosocomial infection with microsphere beds. Lancet 1993;342:241-2.
54. Noble M, Isaac-Reton J, Bryce E. The toilet as a transmission vector of vancomycin-resistant enterococci. J Hosp Infect 1998;40:237-41.
55. Weber D, Rutala W. Role of environmental contamination in the transmission of vancomycin-resistant enterococci. Infect Control Hosp Epidemiol 1997;18:306-9.
56. Sheretz R, Reagen D, Hampton K, Robertson K, Streed S, Hoen H, et al. A cloud adult: the *Staphylococcus aureus* virus interaction revisited. Ann Intern Med 1996;124:539-47.
57. Donskey C. The role of the intestinal tract as a reservoir and source for transmission of nosocomial pathogens. Clin Infect Dis 2004;39:219-26.
58. Layton M, Perez M, Heald P, Patterson J. An outbreak of mupirocin-resistant *Staphylococcus aureus* on a dermatology ward associated with an environmental reservoir. Infect Control Hosp Epidemiol 1993;14:369-75.
59. Centers for Disease Control and Prevention/Healthcare Infection Control Advisory Committee (HICPAC) Guidelines for Environmental Infection Control in Healthcare Facilities. Atlanta, GA: Centers for Disease Control and Prevention; 2002. Available from: www.cdc.gov. Accessed December 20, 2004.
60. Centers for Disease Control and Prevention. Draft Guideline for Isolation Precautions; Preventing Transmission of Infectious Agents in Healthcare Settings, 2004. Federal Register 2004;69:33034.
61. Joint Commission on Accreditation of Healthcare Organizations: Comprehensive Accreditation Manual for Hospitals: The official Handbook. Oakbrook, Illinois. JCAHO; 2004. EC-1.
62. Noskin G, Peterson L. Engineering infection control through facility design. Emerg Infect Dis 2001;7:354-6.
63. Rutala WA, APIC Guidelines Committee. APIC guideline for selection and use of disinfectants. Am J Infect Control 1996;24:313-42.
64. Rutala WA, Stiegel MM, Sarubbi FA, Weber DJ. Susceptibility of antibiotic-susceptible and antibiotic-resistant hospital bacteria to disinfectants. Infect Control Hosp Epidemiol 1997;18:417-21.
65. Rutala W, Weber D. New disinfection and sterilization methods. Emerg Infect Dis 2001;7:348-53.
66. Wulit M, Odenholt I, Walder M. Activity of three disinfectants and acidified nitrite against *Clostridium difficile* spores. Infect Control Hosp Epidemiol 2003;24:765-8.
67. Smith T, Iwen P, Olson S, Rupp M. Environmental contamination with vancomycin-resistant enterococci in an outpatient setting. Infect Control Hosp Epidemiol 1998;19:515-8.
68. Linkin D, Fishman N, Patel J, Merrill J, Lautenbach E. Risk factors for extended-spectrum β-lactamase-producing enterobacteriaceae in a neonatal intensive are unit. Infect Control Hosp Epidemiol 2004;25:781-3.
69. Griffith C, Malik R, Looker N, Michaels B. Environmental surface cleanliness and the potential for contamination during handwashing. Am J Infect Control 2003;31:93-6.
70. Rutala W, Weber D. Surface disinfection: should we do it? J Hosp Infect 2001;48(Suppl A):S64-8.
71. Hota B. Contamination, colonization and cross-colonization: are hospital surfaces reservoirs for nosocomial infection? Clin Infect Dis 2004;39:1182-9.
72. Martineau B. Infection prevention measures. Materials Manage Health Care 2003;13:39-40.
73. ICNA/ADM Working Group. Standards for environmental cleanliness in hospitals. Wylam (UK): Infection Control Nurses' Association and Association of Domestic Management; April 4, 1999.
74. Cryer P. Investing in NHS facilities. Department of Health. The NHS plan, a plan for investment, a plan to reform. London: The Stationery Office; 2000.
75. Malik R, Cooer R, Griffith C. Use of audit tools to evaluate the efficacy of cleaning systems in hospitals. Am J Infect Control 2003;31:181-7.
76. Diekema D, BootsMiller J, Vaughan T, Woolson R, Yankey J, Ernest E, et al. Antimicrobial trends and outbreak frequency in United States hospitals. Clin Infect Dis 2004;38:78-85.