ORIGINAL ARTICLE

Decreasing Operating Room Environmental Pathogen Contamination through Improved Cleaning Practice

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OBJECTIVE. Potential transmission of organisms from the environment to patients is a concern, especially in enclosed settings, such as operating rooms, in which there are multiple and frequent contacts between patients, provider's hands, and environmental surfaces. Therefore, adequate disinfection of operating rooms is essential. We aimed to determine the change in both the thoroughness of environmental cleaning and the proportion of environmental surfaces within operating rooms from which pathogenic organisms were recovered.

DESIGN. Prospective environmental study using feedback with UV markers and environmental cultures.

SETTING. A 1,500-bed county teaching hospital.

PARTICIPANTS. Environmental service personnel, hospital administration, and medical and nursing leadership

RESULTS. The proportion of UV markers removed (cleaned) increased from 0.47 (284 of 600 markers; 95% confidence interval [CI], 0.42–0.53) at baseline to 0.82 (634 of 777 markers; 95% CI, 0.77–0.85) during the last month of observations ($P < .0001$). Nevertheless, the percentage of samples from which pathogenic organisms (gram-negative bacilli, *Staphylococcus aureus*, and *Enterococcus* species) were recovered did not change throughout our study. Pathogens were identified on 16.6% of surfaces at baseline and 12.5% of surfaces during the follow-up period ($P = .998$). However, the percentage of surfaces from which gram-negative bacilli were recovered decreased from 10.7% at baseline to 2.3% during the follow-up period ($P = .015$).

CONCLUSIONS. Feedback using Gram staining of environmental cultures and UV markers was successful at improving the degree of cleaning in our operating rooms.

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During the past decade, there has been an increasing awareness of the role of the hospital environment as a reservoir of multidrug-resistant organisms. These organisms include methicillin-resistant *Staphylococcus aureus* (MRSA), vancomycin-resistant enterococci (VRE), *Clostridium difficile*, and *Acinetobacter baumannii*.[1-7] However, the interactions between healthcare worker's hands, patients, objects, and the hospital environment has, to our knowledge, thus been studied only in intensive care units and wards.[1,5,8,9] There is evidence that the hospital environment, including the operating rooms, is often not cleaned thoroughly or in a manner consistent with relevant hospital policies.[10,11] Nevertheless, regular objective performance feedback can lead to improved cleaning rates. Earlier studies have shown an improvement in cleaning thoroughness from 47% at baseline to almost 80% after instituting structured ongoing monitoring and feedback programs in almost 40 hospitals.[11]

Until recently, no objective evaluation of disinfection has been performed in operating rooms. In a recent study, Jefferson et al[10] evaluated 71 operating rooms in 6 acute care hospitals and found a mean daily cleaning rate of 25% of the objects monitored. This finding is of particular concern, because studies by Loftus and collaborators have shown a correlation between contamination of anesthesia machines and contamination of intravenous stopcocks[12] as well as an association between hand contamination among anesthesia providers and contamination of intravenous stopcocks.[13] As part of interventions put in place to control an outbreak of endemic *A. baumannii* infection primarily involving our surgical and trauma intensive care units, we implemented an

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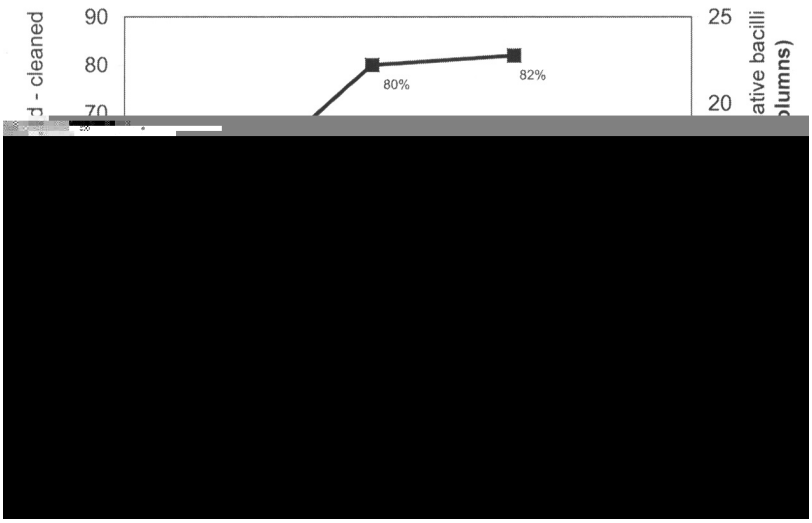

FIGURE 1. Changes in cleaning practices and environmental contamination of the operating rooms. The line indicates the percentage of UV markers removed (cleaned), and the columns indicate the percentage of environmental surface samples from which gram-negative bacilli were recovered.

evaluation of environmental contamination and cleaning practices. As reported elsewhere, this evaluation started in our intensive care units and later expanded to include our operating rooms.[14] The evaluation of environmental contamination and cleaning practices in our operating rooms was achieved by objectively evaluating preintervention cleaning effectiveness and the degree to which improvement in the thoroughness of cleaning influenced bacterial contamination of operating room surfaces.

METHODS

This study was performed from April through December 2011 at Jackson Memorial Hospital, a 1,500-bed teaching hospital affiliated with the University of Miami Miller School of Medicine. The facility has 43 operating rooms, including 33 adult and pediatric, 4 obstetric, and 6 trauma suites. Cleaning of operating rooms was coordinated by the perioperative nursing director (M.R.), who evaluated cleaning practices performed by operating room technicians between surgical procedures and by environmental services staff at the end of the day (terminal cleaning). The administrators who supervised cleaning practices remained consistent throughout the study. Before implementation, the project was presented to the institutional review board, which waived informed consent documentation.

UV markers. A transparent fluorescent gel marking system (DAZO) was used to mark operating room surfaces before the first case of the day, and these surfaces were subsequently evaluated 24 hours later using a UV lamp. Because of the design of the dispenser, the size of the markers remained constant at 2 cm in diameter. Throughout this project, only one member of the Infection Control Department (Y.F.-A.) performed applications and observations of UV markers. Objects tested were selected in accordance with the recommendations of the Association of Perioperative Registered Nurses (AORN) as well as those of the study by Jefferson and collaborators.[10,15] These objects included bed control panels, anesthesia-related equipment (keyboards, knobs, switches, oxygen reservoir bags, and adjacent medication drawers), Mayo stands, over-table lamps, and floors (within 3 feet of the operating room table). As described elsewhere,[16,17] the presence of UV material at 24 hours was considered to represent a lack of cleaning of the object tested. Removal of the UV marker was considered to be evidence of one or more episodes of cleaning of the monitored surfaces.

Environmental cultures. Environmental cultures were obtained before 7 AM from inactive operating rooms that had undergone terminal cleaning the previous night. Objects tested included all areas marked with UV markers. Throughout the project, samples were obtained concomitantly by a team of 2 infection preventionists (Y.F.-A. and G.C.) and a microbiology technologist (D.D.P.). Premoistened 6-inch cotton swabs (Sterile Cotton-Tipped Applicators; MediChoice) were used to culture an area approximately 10 × 10 cm in area. Swab samples were immediately placed in 2 mL of tryptic soy broth (BD Diagnostics) and incubated overnight at 37°C. Broths that showed growth were streaked on blood and MacConkey agar plates (BD Diagnostics). After 48 hours of incubation at 37°C, visible colonies were subcultured and identified by the clinical microbiology laboratory (Vitek II; bioMérieux). For the purpose of this project, pathogens were defined as any gram-negative bacilli, *S. aureus*, or *Enterococcus* species. Objects were deemed positive for skin flora if cultures grew only such organisms as coagulase-negative *Staphylococ-*

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TABLE 1. UV Marker Observations by Month and Object Tested

Variable	Month of observation, proportion (95% CI)				P			
	June	July	August	October	June vs July	July vs August	August vs October	June vs October
Anesthesia equipment								
Anesthesia medication cart	0.38 (0.2–0.6)	0.60 (0.40–0.76)	0.74 (0.54–0.88)	0.7 (0.5–0.84)	.109	.195	.632	.039
Anesthesia machine computer	0.67 (0.45–0.83)	0.9 (0.72–0.97)	0.94 (0.74–0.99)	0.94 (0.76–0.99)	.054	.590	.887	.035
Anesthesia machine switches and knobs	0.25 (0.18–0.34)	0.52 (0.43–0.6)	0.76 (0.67–0.83)	0.77 (0.69–0.83)	.004	.006	.762	<.0001
All other surfaces								
Bed control	0.64 (0.42–0.81)	0.77 (0.57–0.89)	0.89 (0.69–0.97)	0.91 (0.72–0.97)	.252	.184	.851	.042
Mayo stands	0.71 (0.49–0.87)	0.85 (0.65–0.94)	0.91 (0.72–0.98)	0.96 (0.78–0.99)	.2	.36	.387	.044
Intravenous pole	0.55 (0.34–0.74)	0.67 (0.48–0.82)	0.72 (0.51–0.87)	0.79 (0.6–0.91)	.283	.616	.466	.067
Operating room entry door	0.55 (0.34–0.74)	0.75 (0.55–0.88)	0.83 (0.62–0.93)	0.81 (0.62–0.92)	.111	.389	.822	.054
Overhead lamp	0.57 (0.36–0.76)	0.75 (0.55–0.88)	0.91 (0.72–0.98)	0.91 (0.72–0.97)	.144	.106	.880	.025
Floors	0.93 (0.5–0.99)	0.98 (0.4–1.0)	1.0 (NA)	1.0 (NA)	.364	NA	NA	NA
All objects[a]	0.47 (0.42–0.53)	0.67 (0.62–0.71)	0.8 (0.76–0.84)	0.82 (0.77–0.85)	.002	.004	.620	<.0001

NOTE. CI, confidence interval; NA, not available.
[a] Includes anesthesia equipment and floors.

cus species, *Streptococcus viridians*, *Bacillus* species, *Micrococcus* species, or diphteroids.

Educational interventions. Graphic electronic communications of the results of the fluorescent dye marking and the environmental cultures were sent to the environmental services department, the operating room administration, and the hospital administration (including the chief executive officer, chief medical officer, and the chief nursing officers as well as the quality and patient safety division) to monitor and encourage cleaning process improvement. Based on this feedback, verbal and graphic educational programs were performed by the area environmental services director for their staff (all shifts) during July 2011.

Statistics. UV marker data were analyzed using logistic regression by object type. The dependent variable was cleaning status (cleaned vs not cleaned). The independent variable was the month of observation. Contrasts were used to compare adjacent months to determine whether a significant change had occurred. Results are reported as proportions with 95% confidence intervals (CIs). Positive culture results were analyzed with a generalized linear model. The dependent variable was the frequency of isolation of the organism, whereas the independent variable was time period (May through July and August through December). To control for the varying number of objects examined in each room, an offset variable was included. The results are reported as the proportion of contaminated objects (± standard error).

RESULTS

Cleaning thoroughness. Four cycles of observations using UV markers were performed from June through October, 2011 (1 week per month). Overall, 194 operating rooms and 2,820 objects were evaluated during the study. At baseline (June–July, 2011), the proportion of UV marks removed by 24 hours after placement was 0.47 (284 of 600 marks; 95% CI, 0.42–0.53; Figure 1 and Table 1). This proportion increased during and after the educational intervention and reached 0.82 (634 of 777 marks; 95% CI, 0.77–0.85) during the last month of observations ($P < .0001$). The most striking improvement during the study was related to the anesthesia equipment, particularly the cleaning of anesthesia machines, which increased more than 150%, from 0.25 to 0.77 ($P < .0001$). Other objects that showed significant improvement in thoroughness of cleaning included bed control panels, Mayo stands, and overhead lamps. The objects that failed to show clear improvement included floors, intravenous poles, and operating room entry door handles.

Environmental cultures. Over a 9-month period, 427 objects were cultured in 35 operating rooms. Overall, 65 objects (15.2%) had culture results that were positive for pathogens, 246 (57.6%) had cultures that grew skin flora, and 116 (27.2%) had negative culture results (Table 2).

Microbiology. Pathogens identified during the study included *Pseudomonas* species (24 isolates), *Enterobacter aerogenes* (14), *S. aureus* (11), *Enterococcus* species (11), *Acinetobacter* species (8), *Klebsiella pneumoniae* (4), *Escherichia coli* (3), and 10 other gram-negative bacilli, including *Morganella* species, *Stenotrophomonas maltophilia*, *Alcaligenes* species, *Achromobacter* species, *Chryseomonas* species, and *Aeromonas* species. Five (45%) of the 11 *S. aureus* isolates were resistant to methicillin. *Acinetobacter* species were isolated from 8 objects in 7 operating rooms; 6 (86%) of the rooms were trauma

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TABLE 2. Environmental Culture Results by Objects Tested

Variable	Baseline				Follow-up				P^a
	No. (%) of samples with pathogens	No. (%) of samples with skin flora	No. (%) of samples with negative culture result	Total samples cultured	No. (%) of samples with pathogens	No. (%) of samples with skin flora	No. (%) of samples with negative culture result	Total samples cultured	
Anesthesia equipment[b]	6 (11.3)	25 (47.2)	22 (41.5)	53	3 (12.5)	13 (54.2)	8 (33.3)	24	.884
Bed[c]	5 (11.9)	23 (54.7)	14 (33.3)	42	2 (8.3)	12 (50)	10 (41.7)	24	.660
Mayo stands	3 (8.5)	13 (37.1)	19 (54.3)	35	0	7 (58.3)	5 (41.7)	12	.985
Intravenous pumps and poles	8 (17.4)	26 (56.5)	12 (26.1)	46	2 (8.3)	11 (45.8)	11 (45.8)	24	.334
Circulating nurse area	11 (17.5)	47 (74.6)	5 (7.9)	63	2 (5.6)	26 (72.2)	8 (22.2)	36	.136
Operating room entry door	0	21 (95.5)	1 (4.5)	22	1 (8.3)	11 (91.7)	0	12	.980
All objects (excluding floors)	33 (12.6)	155 (59.3)	73 (27.9)	261	10 (7.6)	80 (60.6)	42 (31.8)	132	.998
Floor	14 (63.6)	8 (36.4)	0	22	8 (66.7)	3 (25)	1 (8.3)	12	.863
All objects (including floors)	47 (16.6)	163 (57.6)	73 (25.8)	283	18 (12.5)	83 (25)	43 (29.9)	144	.998

[a] Pathogens at baseline versus pathogens at follow-up.
[b] Includes knobs, switches, keyboard, oxygen reservoir bag, and anesthesia medication cart.
[c] Includes bed control panel and operating room bed.

operating rooms. The objects contaminated with *Acinetobacter* species included intravenous poles (2 isolates), operating room beds (1), Mayo tables (1), and floors (4).

All surfaces excluding floors. Before educational interventions, 33 (12.6%) of 261 objects grew pathogens (Table 2). During the follow-up period, 10 (7.6%) of 132 objects were positive for pathogens ($P = .998$). As shown in Figure 1 and Table 3, identification of gram-negative bacilli significantly decreased from baseline during the study (10.7% vs 2.3%; $P = .015$). The number of samples with gram-positive pathogens and skin flora isolated failed to show statistically significant changes during the study (Tables 2 and 3).

Floors. Thirty-four floor areas were cultured, including 22 at baseline and 12 at follow-up; pathogens were isolated from 63% and 66% of floor areas, respectively (Table 2; $P = .917$). Gram-negative bacilli were identified in 63% of floor samples at baseline and in 41.6% of floor samples at follow-up ($P = .108$).

Educational and environmental services interventions. After 2 cycles of covert baseline data collection, operating room cleaning personnel from all shifts were reeducated regarding cleaning expectations for specific objects and were provided with the UV marker and environmental culture results. All new initiatives to enhance cleaning practice were performed by the directors of nursing and the environmental service managers. Personnel were also informed that regular cleaning surveillances would be ongoing. Other than the regular feedback of results, no major input regarding the cleaning of the operating rooms was provided by the infection control department.

Two main interventions were implemented as a result of the feedback from infection control. First, in July 2011, the anesthesia technologists were made responsible for the cleaning of the anesthesia machine and associated equipment between procedures; this equipment included the anesthesia machines, electrocardiography leads, blood pressure cuffs, intravenous pumps, intravenous poles, and oxygen reservoirs. Second, in September 2011, the cleaning product was changed from 17.2% isopropanolol (CaviWipes; Metrex) to 1 : 10 sodium hypochloride solution (Dispatch; Clorox). Ortho-phenylphenol (Wex-Cide 128; Wexford Labs), which was used for the floors, was the only disinfectant that remained constant throughout 2011. Our hospital's operating room cleaning policies for between procedures and for terminal cleaning, which were developed to be consistent with AORN-recommended protocols, remained unchanged during the study.

DISCUSSION

This project was initially implemented to evaluate the possible role of the operating room environment in the horizontal transmission of *A. baumannii* in our hospital. After confirming episodic surface contamination with this organism, we implemented an evaluation of the thoroughness of cleaning in our operating room areas. Using the results of both fluorescent marking and environmental culture, we developed a structured education and feedback program. This program facilitated improvement of the cleaning process, similar to previously described programs that were implemented for areas other than operating rooms.[11] At baseline, we found

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TABLE 3. Comparison of Type of Organisms Isolated from the Operating Room Environment (Excluding Floors) Based on Study Phase

	Baseline[a]		Follow-up[b]		
Culture finding	Proportion	Standard error	Proportion	Standard error	*P*
Gram-negative bacilli					
Acinetobacter species	0.019	0.009	<0.001	<0.0001	.977
Other gram-negative bacilli	0.088	0.018	0.023	0.013	.034
All gram-negative bacilli	0.107	0.020	0.023	0.013	.015
Gram-positive bacilli					
Enterococcus species	0.015	0.008	0.023	0.013	.610
Staphylococcus aureus	0.019	0.009	0.038	0.017	.289
Skin flora[c]	0.594	0.048	0.606	0.068	.884
Culture negative	0.280	0.033	0.318	0.049	.51

[a] April through July 2011.
[b] October through December 2001.
[c] Skin flora includes organisms such as coagulase-negative *Staphylococcus, Streptococcus viridians, Bacillus species, Micrococcus* species, and diphteroids.

that less than 50% of tested surfaces had been cleaned by 24 hours after target application. Ongoing performance feedback over the next 4 months led to an 82% increase in the cleaning of markers by the final month of follow-up. The significant improvement in cleaning of anesthesia equipment was most likely attributable to the subsequent reassignment of cleaning duties, similar to an intervention previously reported by Baille.[16]

An evaluation of the thoroughness of floor cleaning was included in the study, because earlier observations by our group disclosed the fact that objects that fall onto the floors are frequently placed back either on horizontal work surfaces or on patients themselves. For example, intravenous tubing frequently contacts the floor as it drapes between the patient and the intravenous pump (Figure 2). Anesthesia providers have frequent and multiple contacts with such objects, including intravenous tubing, mixture controls, and intravenous administration hubs as well as with patients and horizontal surfaces. Consequently, the operating room floor can potentially transmit organisms to the patient through inadvertent contamination of surfaces during routine care.

During the intervention, we observed decreased contamination of surfaces by gram-negative bacilli. The prevalence of contamination with *S. aureus, Enterococcus* species, or skin flora failed to show a significant change, possibly because of the relative paucity of cultures positive for the former 2 organisms at any point in the study. The ubiquitous nature of coagulase-negative *Staphylococcus* species, ongoing contamination of surfaces because of transient hand colonization of healthcare workers, or contaminated circulating air may have limited our ability to evaluate the impact of the interventions on skin organisms.

Other studies have documented similar improvement in bacterial contamination of surfaces in response to improved thoroughness of disinfection. Hayden and colleagues studied the impact of covert cleaning observations on contamination of the environment by VRE.[1] The authors found that a 75% improvement in the thoroughness of cleaning was associated with a 73% ($P = .0001$) decrease in near-patient environmental contamination with VRE.[1] Likewise, Goodman and collaborators used a fluorescent monitoring and feedback program in 10 intensive care units within a single hospital.[17] In their study, an 80% improvement in the thoroughness of cleaning was associated with a 61% ($P = .02$) decrease in environmental contamination with MRSA and VRE.[17] In our study, although an 87% improvement in cleaning thoroughness was associated with a concomitant 80% decrease in environmental contamination by gram-negative bacilli, we were unable to document a clearly significant decrease in *S. aureus* or enterococcal environmental contamination, possibly for the reasons noted above. Because of the likelihood of ongoing intestinal flora contamination of the operating room environment by patients, we believe that it is likely that the decreased contamination by gram-negative bacilli occurred as a result of improved thoroughness of surface cleaning.

Several limitations of our study should be noted. Because of scheduling and infection control staff limitations, cultures and evaluation of cleaning thoroughness were performed on alternate weeks. Although this limitation could have theoretically blunted the magnitude of our findings, the impact of this limitation would be expected to be equal before and after the improvement in cleaning thoroughness. Although we observed substantial improvement in the degree of contamination with gram-negative bacilli, the manner in which the study was performed may have prevented an accurate assessment of the impact of our intervention on other organisms. Although additional studies may clarify the relevance of this limitation, the fact that we documented an 80% decrease in environmental contamination by gram-negative organisms during a time in which the thoroughness of environmental cleaning improved to 82% is similar to the studies previously cited. The sensitivity of our analysis might also

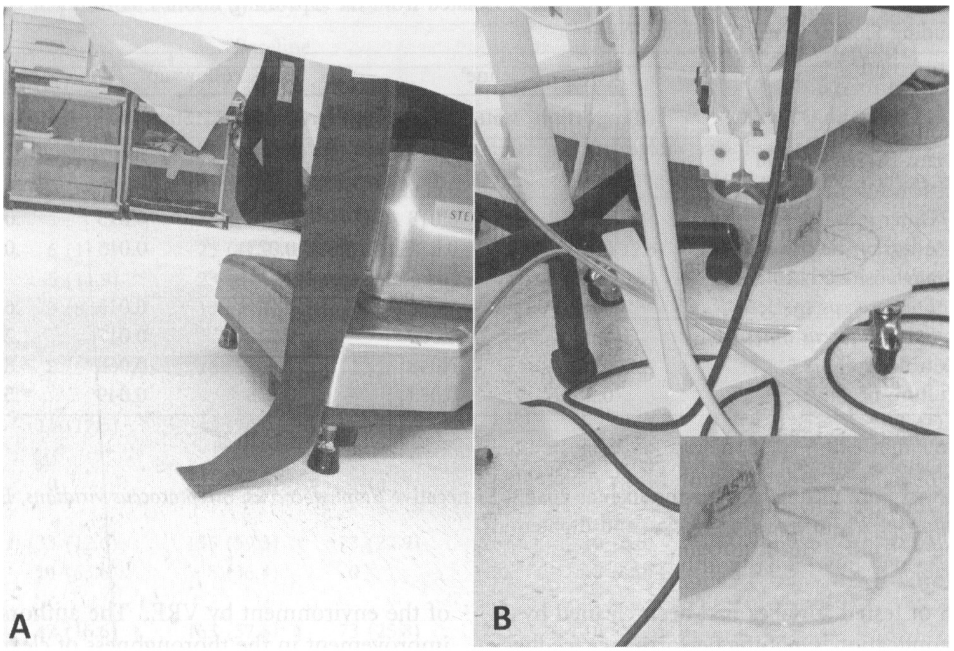

FIGURE 2. Interactions between objects and operating room floors. *A*, Strap used to fasten a patient to the operating room bed is shown draping over the floor. *B*, Intravenous tubing and other leads are shown curling on the operating room floor.

have been impacted by an underestimation of the bioburden associated with the small surfaces of the switches and monitors of the anesthesia machines. Additionally, culture results were analyzed as dichotomous rather than continuous variables, which potentially limited the sensitivity of our evaluation. Although future studies may wish to incorporate quantitative cultures, the generally very low bioburden of environmental surfaces in healthcare settings might limit the sensitivity of the analysis to detect bioburden changes after interventions without evaluating a very large number of surfaces. Although the fact that chemical neutralizers were not used could have potentially blunted the sensitivity of our analysis, such an impact would have been constant throughout the study. Finally, it is important to note that our findings relate to a fairly brief study in a single institution.

The finding that only 74% of surfaces harbored viable organisms before the intervention is similar to observations made by others who have found 31%–95% of random healthcare surfaces other than floors to either be sterile or to harbor <2.5 aerobic bacterial colonies per centimeter.[2,18,19] Because of our findings, we would agree with others who have noted that failure to take into account the level of cleanliness of surfaces before cleaning may lead to an overestimation of the efficacy of cleaning protocols when using culture-based or adenosine triphosphate evaluation systems to study the thoroughness of cleaning practices.[20]

Education combined with objective feedback using UV markers has previously been shown to improve the thoroughness of environmental cleaning in a range of healthcare settings, including general medical wards, intensive care units, operating room, and emergency medical vehicles.[10,11,21,22] During these studies, improvement was accomplished exclusively through ongoing objective performance feedback to the environmental services staff. Although the sustainability of improved hygienic practice needs to be evaluated more extensively,[23] preliminary findings suggest that the impact of such programs may deteriorate once feedback is no longer ongoing.[24,25] The only study to date that objectively evaluated the thoroughness of terminal room cleaning in the operating room setting showed that only 25% of high-touch surfaces were cleaned according to policy.[10] A possible explanation for the difference between our finding (47% thoroughness of cleaning at baseline) and the findings of Jefferson et al[10] might be the fact that environmental culture results were provided to the staff on a single occasion before baseline fluorescent marker evaluation was initiated, whereas the evaluations reported by Jefferson et al[10] were performed covertly.

Based on our findings and existing literature,[10,12,13] operating rooms might not be the clean settings that healthcare providers commonly believe them to be. Related findings within operating rooms have been recently described by Loftus and colleagues.[12,13] They described bacterial transmission from patients to the environment in 89% of instances.[12] These findings illustrate the fact that interactions between patient body surfaces, hands, and the operating room environment play an important role in the transmission of bacteria. In their studies, these authors described transmission of organisms to intravenous stopcocks in 11.5% of patients, with approximately half of these cases associated with the anesthesia providers.[13] Nevertheless, studies have yet to be

performed that systematically evaluate the potential for relatively more contaminated operating room surfaces leading to greater rates of hospital-acquired infection. During 2011, our hospital observed a decreased number of acquisitions of carbapenem-resistant *A. baumannii* (especially in our surgical units) as well as a reduced rate of neurosurgical wound infections (data not shown). However, many other interventions aimed at decreasing the same outcomes were implemented concomitantly. Therefore, we are unable to quantify the independent impact of our program on these infections.

In conclusion, this study demonstrated for the first time, to our knowledge, that simple programmatic improvement in the thoroughness of disinfection cleaning in the operating room area can significantly decrease surface contamination with gram-negative organisms that have the potential for transmission to patients and healthcare workers. Because of the recent finding that subsequent occupants of an intensive care unit room have a substantial risk of acquiring either *Pseudomonas* or *Acinetobacter* species from previous occupants of the room,[26] our results suggest that additional studies may be warranted to clarify the environmental epidemiology and risks related to the possible transmission of surface-contaminating pathogens from operating room surfaces that have not been properly cleaned. Furthermore, studies have yet to be performed to objectively quantify the risk associated with environmental cleaning practices that are not in accordance with current AORN recommendations.[15] However, our findings and those of Jefferson et al[10] suggest that there may be a need to more thoroughly evaluate both process and outcome issues related to the role of the operating room environment in pathogen transmission.

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Potential conflicts of interest. P.C. has served as a consultant for Steris, Ecolab, and the American Society for Healthcare Environmental Services. 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.

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