MAJOR ARTICLE

Reduction in Acquisition of Vancomycin-Resistant Enterococcus after Enforcement of Routine Environmental Cleaning Measures

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Background. The role of environmental contamination in nosocomial cross-transmission of antibiotic-resistant bacteria has been unresolved. Using vancomycin-resistant enterococci (VRE) as a marker organism, we investigated the effects of improved environmental cleaning with and without promotion of hand hygiene adherence on the spread of VRE in a medical intensive care unit.

Methods. The study comprised a baseline period (period 1), a period of educational intervention to improve environmental cleaning (period 2), a "washout" period without any specific intervention (period 3), and a period of multimodal hand hygiene intervention (period 4). We performed cultures for VRE of rectal swab samples obtained from patients at admission to the intensive care unit and daily thereafter, and we performed cultures of environmental samples and samples from the hands of health care workers twice weekly. We measured patient clinical and demographic variables and monitored intervention adherence frequently.

Results. Our study included 748 admissions to the intensive care unit over a 9-month period. VRE acquisition rates were 33.47 cases per 1000 patient-days at risk for period 1 and 16.84, 12.09, and 10.40 cases per 1000 patient-days at risk for periods 2, 3, and 4, respectively. The mean ($\pm$SD) weekly rate of environmental sites cleaned increased from 0.48 ± 0.08 at baseline to 0.87 ± 0.08 in period 2; similarly high cleaning rates persisted in periods 3 and 4. Mean ($\pm$SD) weekly hand hygiene adherence rate was 0.40 ± 0.01 at baseline and increased to 0.57 ± 0.11 in period 2, without a specific intervention to improve adherence, but decreased to 0.29 ± 0.26 in period 3 and 0.43 ± 0.1 in period 4. Mean proportions of positive results of cultures of environmental and hand samples decreased in period 2 and remained low thereafter. In a Cox proportional hazards model, the hazard ratio for acquiring VRE during periods 2–4 was 0.36 (95% confidence interval, 0.19–0.68); the only determinant explaining the difference in VRE acquisition was admission to the intensive care unit during period 1.

Conclusions. Decreasing environmental contamination may help to control the spread of some antibiotic-resistant bacteria in hospitals.

Antibiotic resistance is a worldwide problem that threatens successful treatment of hospitalized patients. Multiple strategies to limit the spread of antibiotic-resistant pathogens, either as single or bundled interventions, have been tested. Among these are active surveillance to identify and isolate colonized patients [1, 2], efforts to increase hand hygiene adherence [3], modifications of antibiotic policies [4], and the routine use of gloves for patient care [5]. Interpretation of many studies is hampered, because the studies were performed during outbreaks [1], involved implementation of multiple interventions simultaneously, or failed to determine relevant variables and to account for interdependency of observations in statistical analyses [6, 7].

The role of environmental contamination in the epidemiology of antibiotic-resistant pathogens, although it has received media and political attention, has received relatively little scientific attention [8]. Although several studies have demonstrated contamination of the inanimate environment of colonized patients [9–12], the direction of spread between patients and fomites has been mostly unresolved. Using vancomycin-resistant entero-

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Table 1. Characteristics of patients and study periods in a study of acquisition of vancomycin-resistant enterococcus (VRE) after enforcement of routine environmental cleaning measures.

Variable	Period 1	Period 2	Period 3	Period 4	P[a]
Duration, days	58	58	57	82	
No. of patients at start of period	17	16	11	21	
Admissions to MICU					
All	146	136	157	244	
Mean admissions per day	2.52	2.34	2.75	2.98	
Duration of MICU stay					
Mean days ± SD	5.88 ± 8.66	5.67 ± 10.76	4.76 ± 5.09	4.95 ± 5.43	.38
Median	3	4	3	3	
Duration of period, patient-days	957	749	797	1209	
Daily occupancy in MICU, mean days ± SD	17.02 ± 2.39	17.91 ± 1.88	15.4 ± 2.89	16.17 ± 2.68	.55
APACHE II score, mean ± SD	19 ± 9	18 ± 8	18 ± 8	18 ± 8	.65
Patients with contact isolation, mean patients per day ± SD					
All	4.97 ± 1.26	5.57 ± 2.24	4.67 ± 1.77	3.49 ± 1.39	.06
Patients with contact isolation for VRE	4.07 ± 1.25	3.02 ± 1.56	2.19 ± 0.99	1.01 ± 0.71	<.001
Patients receiving enteral feeding, mean patients per day ± SD	7.84 ± 1.9	4.27 ± 1.74	3.79 ± 1.58	4.68 ± 1.52	<.001

NOTE. Period 1 was a baseline period (5 March–1 May 2001; duration, 58 days). Period 2 included environmental hygiene intervention (31 May–27 July 2001; duration, 58 days). Period 3 was a "washout" period in which there was no intervention (23 August–18 October 2001; duration, 57 days). Period 4 included hand hygiene intervention (8 November–7 February 2002; duration, 82 days). MICU, medical intensive care unit.

[a] P values are for comparisons of period 1 to periods 2–4.

cocci (VRE) as a marker organism, we investigated the effects of improved environmental cleaning with and without enforced adherence to hand hygiene on the spread of VRE in a medical intensive care unit (MICU) with high-level endemicity.

METHODS

Study design. We performed a pre- and postintervention study in the 21-bed MICU of Rush University Medical Center (RUMC), a 700-bed tertiary care teaching hospital in Chicago, Illinois. Period 1 (5 March–1 May 2001; duration, 58 days) served as a baseline period, during which there were no specific interventions. During this time, we observed that routine daily environmental cleaning was often incomplete. We devised a program to improve cleaning that was phased in over a 30-day period and was fully implemented in period 2 (31 May–27 July 2001; duration, 58 days).

Daily cleaning comprised wiping or mopping all accessible surfaces—except windows, walls, ceiling, and drapes—with a clean cloth or mop soaked in the standard hospital quaternary ammonium detergent disinfectant (Virex; SC Johnson). Bed rails, infusion pumps, countertops, door handles, telephones, and other items were cleaned similarly. Housekeepers used 8–12 cloths per room. Separate buckets of cleaning solution were used for the floor. Buckets of cleaning solution and mop heads were changed every 3 rooms and after every isolation room. Isolation rooms were cleaned last.

The study intervention consisted of in-services to housekeepers about the importance of environmental cleaning (we emphasized thorough cleaning of surfaces that were likely to be touched by patients or health care workers) and increased monitoring of housekeeper performance. Respiratory therapists were recruited to clean ventilator control panels daily. Educational sessions were held for nurses and other MICU staff on the problem of VRE and on the intervention, instructing staff in ways in which to assist housekeepers (e.g., moving an item from a surface so that the surface could be cleaned).

Period 3 (23 August–18 October 2001; duration, 57 days) served as a "washout" period, without any specific intervention. It was followed by a 21-day phase-in period for the hand hygiene campaign, which comprised mounting alcohol gel dispensers (Stat-Rinse Antiseptic Hand Gel; Richmond Laboratories) throughout common areas, within patient rooms, and at every room entrance; educational sessions for MICU staff and rotators; and motivational brochures, buttons, wall posters, and games. These efforts continued through period 4 (8 November 2001–7 February 2002; duration, 82 days). After 1 month, a bar chart of staff hand hygiene adherence was posted and updated weekly.

Previous studies had identified several relevant risk factors for acquisition of VRE, such as antibiotic use, enteral feeding, and colonization pressure [13–15]. These variables were, therefore, carefully determined. To gauge comparability of patients during study periods, we measured each patient's APACHE II score [16] and length of stay. Because other studies have iden-

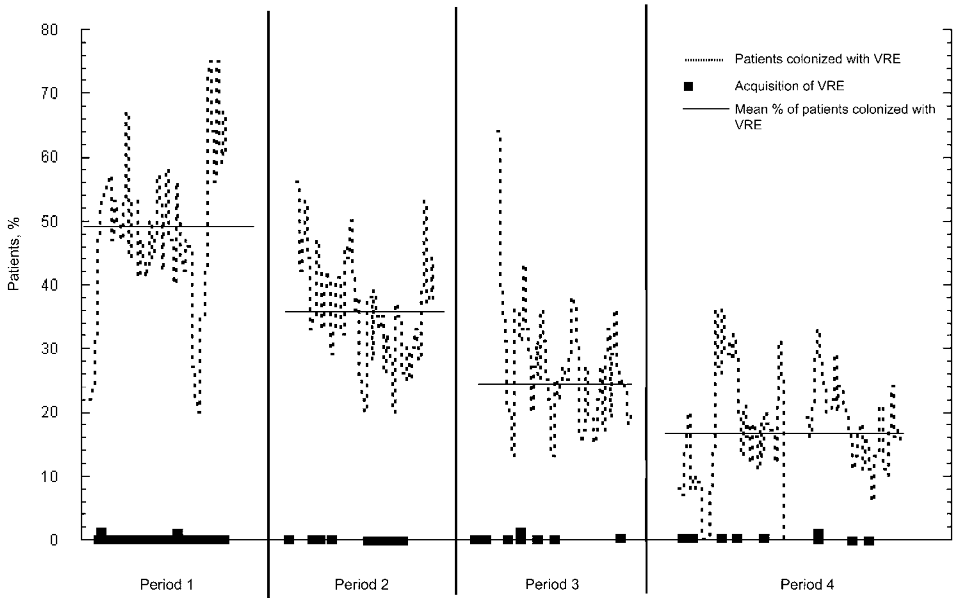

Figure 1. Daily percentage of patients colonized with vancomycin-resistant enterococcus (VRE), daily acquisition of rectal colonization with VRE, and mean percentage of patients colonized with VRE, by period. Period 1 was a baseline period (5 March–1 May 2001; duration, 58 days). Period 2 included environmental hygiene intervention (31 May–27 July 2001; duration, 58 days). Period 3 was a "washout" period in which there was no intervention (23 August–18 October 2001; duration, 57 days). Period 4 included hand hygiene intervention (8 November–7 February 2002; duration, 82 days).

tified understaffing as a risk factor for nosocomial infection [17–19], we calculated median nurse-to-patient ratios and permanent-to-temporary staff nurse ratios for the 2 days immediately before each VRE acquisition. Finally, we determined the daily proportion of patients in contact isolation.

The study was approved by the institutional review board of RUMC. Informed consent was obtained before samples from health care workers' hands were cultured; consent was waived for other study participants.

Microbiologic monitoring. We performed cultures of rectal swab samples from each patient within 2 days after MICU admission and daily to determine VRE colonization. To prevent bias in patient care, medical staff were not informed of study surveillance culture results. Patients with a VRE-positive clinical culture were placed in contact isolation according to Centers for Disease Control and Prevention guidelines [20]. Acquisition rates of VRE were expressed as the number of acquisitions per 1000 patient-days at risk during each study period; only non-colonized patients were considered to be at risk.

Twice weekly, up to 6 rooms of VRE-colonized patients were selected for culture; if fewer than 6 VRE-colonized patients were in the MICU, samples from the rooms of VRE-negative patients were cultured. We attempted to culture samples from rooms no more than once per week and to select rooms of VRE-negative patients systematically, so that samples from as many different occupied rooms as possible were cultured. Eight predetermined environmental sites—bed rails, over-bed table, infusion pump, clean countertop (i.e., where intravenous medications and solutions are prepared), soiled countertop (i.e., countertop adjacent to sink), soap dispenser, drawer handles, and the inside handle to the door of the room—were sampled by rubbing a rayon swab moistened with liquid Stuarts medium (Copan Diagnostics) over a 50-cm^2 area, and the samples were cultured in enrichment broth [21]. The chosen sites were found in a previous study to be contaminated frequently [22]. On days when environmental cultures were obtained, we cultured the gloved or ungloved hands of 6 MICU health care workers by a modified "glove juice" technique [23]. All health care workers in the MICU were eligible to participate. Microbiologic details (including sensitivities) of culture methods are reported elsewhere [21].

Monitoring adherence to infection-control measures. We observed housekeeper performance during all study periods and on each day of the week. We attempted to observe cleaning of all rooms that were cultured and to divide our observations proportionally among housekeepers according to the number of rooms they cleaned. We noted whether each of 8 selected environmental sites was cleaned and recorded results as "cleaned," "not cleaned," "not applicable" (i.e., item not present), or "not observed." Per week, the fraction of items scored as "cleaned" and "not cleaned" was calculated. If, after being observed, a housekeeper asked about his or her performance, research staff provided immediate specific feedback (e.g., "You forgot to clean the countertop").

Hand hygiene observations were made by research staff at various times of day and week to include all shifts. An obser-

Table 2. Patient colonization with vancomycin-resistant enterococcus (VRE), by study period.

Variable	Period 1	Period 2	Period 3	Period 4	P[a]
Patients with VRE colonization					
At start of period	4	8	6	4	
At admission to MICU	29	30	18	31	
MICU admission rate for patients with VRE colonization, admissions per day	0.51	0.53	0.32	0.38	.13
Patients with VRE acquisition after admission to MICU	16	10	7	10	
No. of patient-days at risk for VRE	478	594	579	962	
Rate of VRE acquisition, acquisitions per 1000 patient-days	33.47	16.84	12.09	10.4	
Days until VRE acquisition					
Mean ± SD	8.38 ± 9.42	5.9 ± 4.43	5.86 ± 3.58	4.3 ± 1.77	.38
Median	5	4.5	4	4	.45
Daily colonization pressure, mean value ± SD[b]	0.49 ± 0.12	0.36 ± 0.08	0.26 ± 0.09	0.18 ± 0.08	<.0001

NOTE. Data are no. of patients, unless otherwise indicated. Period 1 was a baseline period (5 March–1 May 2001; duration, 58 days). Period 2 included environmental hygiene intervention (31 May–27 July 2001; duration, 58 days). Period 3 was a "washout" period in which there was no intervention (23 August–18 October 2001; duration, 57 days). Period 4 included hand hygiene intervention (8 November–7 February 2002; duration, 82 days). MICU, medical intensive care unit.

[a] P values are for comparisons of period 1 to periods 2–4.

[b] Daily colonization pressure is defined as the prevalence of patients colonized with VRE each day.

vation began when a health care worker entered a patient's room and was observed in an activity that involved contact with an object or person and ended when that health care worker completed the activity. Monitored variables included hand cleansing (with soap and water or alcohol gel) before and after contact with the patient or environment, donning gowns, and use and removal of gloves.

Statistical analysis. Categorical variables were analyzed by χ^2 statistics. Continuous variables were analyzed by Student's t test or the Mann-Whitney U test. Acquisition rates of VRE were compared using a multivariate Cox proportional hazard model submitting all variables with $P < .10$. The model calculates hazard ratios and 95% CIs.

RESULTS

Patients. A total of 748 admissions to the MICU were studied. Sixty-five patients were in the MICU when a study period commenced, and 683 were admitted to the MICU during the study (table 1). Daily admission rates were comparable for the 4 study periods (ranging from 2.34 admissions per day in period 2 to 2.98 admissions per day in period 4), as were mean daily occupancies (±SD) in the MICU, which ranged from 15.4 ± 2.89 in period 3 to 17.9 ± 1.88 in period 2. Mean duration of stay (±SD) varied from 4.8 ± 5.1 days (median duration of stay, 3 days) in period 3 to 5.9 ± 8.7 days (median duration of stay, 4 days) in period 1 ($P = .38$).

Patient colonization with VRE. A total of 3067 rectal cultures were obtained. Ninety percent of patients admitted to the MICU had cultures performed at least once. Excluding the 10% of patients who never had cultures performed (usually because of MICU stays shorter than 24 h), 99.4% of planned cultures were performed. The median time between cultures was 1 day.

Forty-three patients acquired VRE colonization in the MICU (figure 1). Acquisition rates were 33.47 cases per 1000 patient-days at risk in period 1 and decreased to 16.84, 12.09, and 10.40 cases per 1000 patient-days at risk in periods 2, 3, and 4, respectively. The duration until acquisition did not change significantly ($P = .45$) (table 2).

Daily proportions of patients in MICU who were colonized with VRE (i.e., colonization pressure) ranged from 7% to 75% (figure 1). The mean colonization pressure (±SD) decreased during the 4 study periods; it was 0.49 ± 0.12 patients per day in period 1, 0.36 ± 0.08 patients per day in period 2, 0.26 ± 0.09 patients per day in period 3, and 0.18 ± 0.08 patients per day in period 4 (table 2). Daily admission rates of patients colonized with VRE decreased over time, from 0.51 and 0.53 patients per day in periods 1 and 2, respectively, to 0.32 and 0.38 patients per day in periods 3 and 4, respectively. The rate of VRE in clinical cultures of samples obtained from patients in the MICU decreased from 12.7 isolates per 1000 patient-days in period 1 to 7.3 isolates per 1000 patient-days in period 4. In comparison, the rate of VRE in clinical cultures of samples from hospitalized patients who were not admitted to the MICU was 1.29 and 1.49 isolates per 1000 patient-days during periods 1 and 4, respectively.

Interventions. We observed 485 cleaning episodes (table 3). Although 7 housekeepers worked in the MICU during the study, 60% of observations were of a single housekeeper who cleaned the majority of rooms. The time required to clean a room remained stable at 20–25 min for all periods. Mean en-

Table 3. Interventions and bacterial contamination with vancomycin-resistant enterococcus (VRE), by study period.

Intervention, variable	Period 1	Period 2	Period 3	Period 4	P[a]
Environmental cleaning					
No. of observations	53	160	159	113	
Mean no. of observations per week ± SD	6.6 ± 3.3	20 ± 7.4	18.9 ± 5.1	8.7 ± 4.0	<.0001
Environmental cleaning rate, mean ± SD[b]	0.48 ± 0.08	0.87 ± 0.08	0.85 ± 0.11	0.83 ± 0.09	<.0001
Environmental contamination					
No. of cultures	1646	1346	1462	1697	
Environmental contamination rate[c]					
Before cleaning, mean ± SD	0.15 ± 0.08	0.07 ± 0.05	0.05 ± 0.04	0.06 ± 0.05	<.0001
After cleaning, mean ± SD	0.1 ± 0.06	0.04 ± 0.04	0.03 ± 0.02	0.04 ± 0.04	<.0001
Cultures of samples from rooms with VRE-positive patients					
No. of cultures	1215	960	902	756	
Cultures positive for VRE, no. (%) of cultures	287 (23.6)	112 (11.7)	92 (10.2)	127 (16.8)	<.0001
Cultures of samples from rooms with VRE-negative patients					
No. of cultures	431	386	560	941	
Cultures positive for VRE, no. (%) of cultures	22 (5)	3 (0.7)	5 (0.9)	22 (2.3)	<.0001
Hand hygiene adherence					
No. of observations	136	138	130	375	
Hand hygiene adherence rate before or after contact, mean ± SD[d]	0.40 ± 0.01	0.57 ± 0.11	0.29 ± 0.26	0.43 ± 0.1	.165
Hand hygiene adherence rate before or after contact or glove use, mean ± SD	0.59 ± 0.12	0.67 ± 0.14	0.48 ± 0.26	0.54 ± 0.14	.013
Hand contamination					
No. of cultures	94	96	102	132	
Hand contamination rate, mean ± SD[e]	0.55 ± 0.22	0.11 ± 0.11	0.1 ± 0.09	0.1 ± 0.11	<.0001

NOTE. Period 1 was a baseline period (5 March–1 May 2001; duration, 58 days). Period 2 included environmental hygiene intervention (31 May–27 July 2001; duration, 58 days). Period 3 was a "washout" period in which there was no intervention (23 August–18 October 2001; duration, 57 days). Period 4 included hand hygiene intervention (8 November–7 February 2002; duration, 82 days).

[a] P values are for comparisons of period 1 to periods 2–4.
[b] Environmental cleaning rate is defined as the no. of sites cleaned/no. of sites monitored.
[c] Environmental contamination rate is defined as the no. of sites with cultures positive for VRE/no. of sites cultured.
[d] Hand hygiene adherence rate is defined as the no. of observations confirming adherence to hand hygiene requirements/no. of observations.
[e] Hand contamination rate is defined as the no. of cultures positive for VRE/no. of cultures performed.

vironmental cleaning rates (defined as the number of sites cleaned divided by the number of sites monitored) increased from 0.48 at baseline to 0.87 in period 2 ($P < .0001$; table 3). Although cleaning was not specifically promoted, similarly high cleaning rates persisted through periods 3 and 4.

Increased environmental cleaning was associated with reduced growth of VRE from environmental cultures. At baseline, weekly contamination rates were 0.15 and 0.1 for samples obtained before and after cleaning, respectively. Culture positivity decreased to 0.07 and 0.04 for before and after cleaning in period 2 and then remained at low levels during periods 3 and 4. The colonization status of patients was highly associated with the likelihood of environmental contamination; VRE were recovered 7 times as frequently from cultures of samples obtained from the rooms of VRE-positive patients versus VRE-negative patients (table 3).

We made 779 hand hygiene observations. Weekly hand hygiene adherence rate before or after patient contact was a mean of 0.40 at baseline. Without a specific policy to increase hand hygiene adherence, mean weekly adherence rate (defined as the number of observations confirming hand hygiene before or after contact divided by the number of hand hygiene observations) increased to 0.57 in period 2 ($P < .0001$), but decreased during period 3 to 0.29. During period 4, when hand hygiene adherence was specifically promoted, mean weekly adherence rate increased again to 0.43, comparable to adherence at baseline. When glove use or hand cleansing defined adequate hand hygiene, mean weekly adherence rates were 0.59 at baseline, increased to 0.67 in period 2, and then dropped to 0.48 and 0.54 in periods 3 and 4, respectively. Hand contamination, expressed as the weekly mean number of VRE-positive samples (±SD), was 0.55 ± 0.22 at baseline and decreased to 0.11 ± 0.11 in period 2, 0.1 ± 0.09 in period 3, and 0.1 ± 0.11 in period 4 (table 3).

Antibiotic use, enteral feeding, and nursing care. Approximately 50% of patients received antibiotics while at risk for VRE acquisition (table 4). Antibiotic use in the different study periods was comparable for all agents, except for clindamycin,

Table 4. Antibiotic use in a study of acquisition of vancomycin-resistant enterococcus (VRE), by study period.

Variable	No. (%) of patients: Period 1 (n = 130)	Periods 2–4 (n = 467)	All periods (n = 597)	P
Antimicrobial agent				
Penicillin	30 (23.1)	132 (28.3)	162 (27.1)	.24
Cephalosporin	34 (26.2)	105 (22.5)	139 (23.3)	.38
Vancomycin	23 (17.7)	99 (21.2)	122 (20.4)	.38
Clindamycin	12 (9.2)	22 (4.7)	34 (5.7)	.05
Imipenem-meropenem	4 (3.1)	24 (5.1)	28 (4.7)	.33
No. of antibiotics received				.90[a]
0	65 (50)	223 (47.8)	288 (48.2)	
1–2	50 (38.5)	189 (40.5)	239 (40.0)	
⩾3	17 (13.1)	55 (11.8)	72 (12.1)	

NOTE. Data for the same patient can appear in multiple rows because of combined use of antibiotics. Period 1 was a baseline period (5 March–1 May 2001; duration, 58 days). Period 2 included environmental hygiene intervention (31 May–27 July 2001; duration, 58 days). Period 3 was a "washout" period in which there was no intervention (23 August–18 October 2001; duration, 57 days). Period 4 included hand hygiene intervention (8 November–7 February 2002; duration, 82 days).

[a] P value listed is for comparison of all 3 categories of antibiotic use.

which was used more frequently during period 1 (9.2% in period 1 vs. 4.7% in periods 2–4; $P = .05$). The number of antibiotics per patient was also comparable in the 4 study periods (table 4).

Mean daily proportion of patients receiving enteral feeding ($\pm$SD) decreased during the study, from 7.84 $\pm$ 1.9 in period 1, to 4.27 $\pm$ 1.74 in period 2, to 3.79 $\pm$ 1.58 in period 3, and to 4.68 $\pm$ 1.52 in period 4 ($P < .0001$). There was no statistically significant difference in the median ratio of nurse-to-patient ($P = .68$) or of permanent-to-temporary nursing staff ($P = .06$) during the 2 days before a VRE acquisition versus at other times.

Multivariate analysis. Acquisition of VRE was used as a patient-specific end point in the multivariate analysis. Acquisition rates decreased significantly after the baseline period and then remained stable in periods 2, 3, and 4. With regard to the interventions, environmental cleaning was significantly improved in periods 2–4, compared with baseline. Although adherence to hand disinfection also increased during period 2, high adherence did not persist and was lowest during period 3. Therefore, environmental cleaning was considered to be the sole intervention, and acquisition rates during the baseline period and during the combined periods 2–4 were compared. The effects of this intervention on VRE-acquisition were potentially confounded by the greater use of enteral feeding and clindamycin during period 1. Daily proportions of enteral feeding were used to calculate a mean value for these days for the time at risk of VRE-acquisition for each individual patient, with subdivision of these mean values into 3 classes (0–0.25; 0.26–0.35; 0.36–1). Clindamycin use was entered as a patient-specific binomial value. Colonization pressure and environmental contamination were considered to be intermediates of the intervention and, therefore, not considered as confounders for acquisition.

Acquisition rates were 16 (12.3%) of 130 patients during the baseline period and 26 (5.6%) of 467 patients in periods 2–4. In Cox proportional hazards analysis, the hazard ratio for acquisition of VRE during periods 2–4 was 0.36 (95% CI, 0.19–0.68; $P = .0017$). Adding clindamycin, enteral feeding, or both to the model did not affect the hazard ratios (figure 2), nor did inclusion of other antibiotics. Therefore, admission during period 1, compared with periods 2–4, was the only determinant explaining the difference in VRE acquisition.

DISCUSSION

We found that enforcing routine environmental cleaning measures was associated with less surface contamination with VRE, cleaner health care worker hands, and a significant reduction in VRE cross-transmission in an MICU with high-level VRE endemicity. These improvements occurred despite ongoing admission of VRE-colonized patients to the MICU and only moderate rates of health care worker adherence to proper hand hygiene. The intervention was simple and well-accepted by housekeepers and MICU staff members, and it was durable for at least 9 months. It required neither a measurable increase in labor nor an extraordinary cleaning method, and it avoided the cost and potential hazard to patients of surveillance and isolation programs, such as "search and destroy" [24, 25].

Although several published studies have implicated contaminated fomites as vectors for transmission of VRE during outbreaks [26–28], it has been more difficult to prove the significance of environmental contamination in cross-acquisition of VRE in settings of endemicity. VRE have been found frequently and sometimes persistently on a variety of inanimate surfaces in different health care environments [10, 15, 29–32], and they have been determined to contaminate gloved or ungloved hands of health care workers who touched these sites [33–35]. Health care workers are nearly as likely to contaminate their gloves or hands after touching environmental surfaces in a VRE-colonized patient's room as when they touch the patient [36]. Subsequent transfer of VRE to a clean site on a patient or in the environment occurs with comparable efficiency regardless of whether the source of contamination is a patient or an environmental site, despite the overall lower density of environmental contamination [21]. Admission to a contaminated MICU room was a risk factor for VRE acquisition in 1 study [37].

Our study provides further support for the importance of an environmental reservoir and of environmental degerming to prevent endemic cross-transmission of VRE. In a Cox proportional hazards model, the only factor that explained the difference in patient acquisition of VRE over time was admission to the MICU during the baseline period, prior to imple-

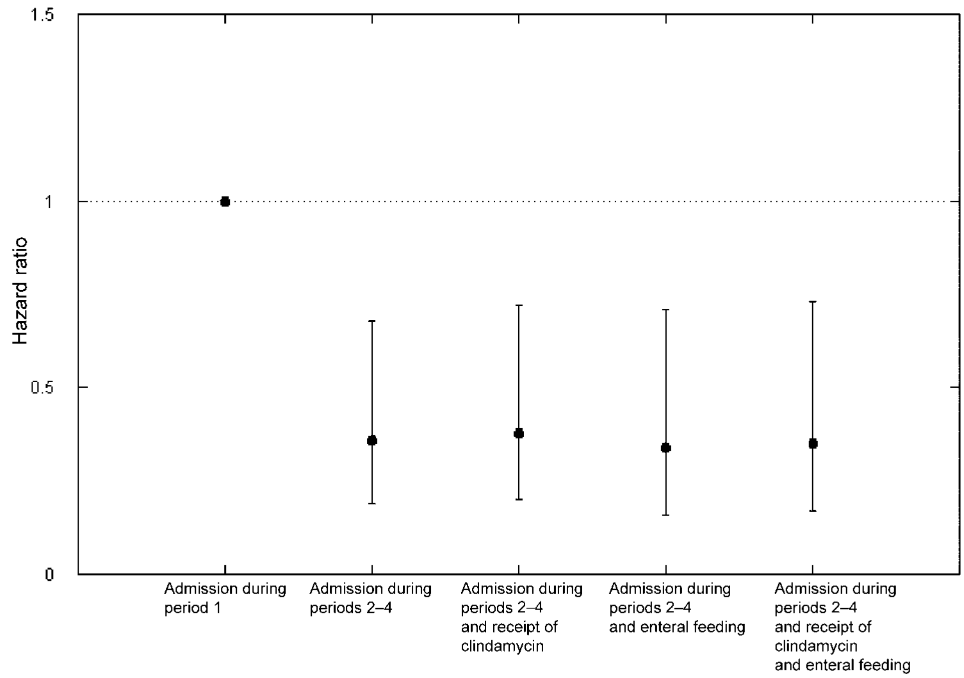

Figure 2. Cox proportional hazards model of acquisition of vancomycin-resistant enterococcal rectal colonization, showing hazard ratios and 95% CIs *(bars).* During periods 2–4, environmental cleaning improved significantly. Admission during period 1, compared with during periods 2–4, was the only determinant explaining the difference in the rate of acquisition of vancomycin-resistant enterococcus in this model.

mentation of the environmental cleaning intervention. This finding is strengthened by the large number of patients studied, the many samples obtained for culture, the sensitivity of the culture methods used, the careful attention to potentially confounding factors, and the exhaustive monitoring of adherence to the intervention.

It is important to note that the standard environmental cleaning procedure followed in our MICU was the "bucket method," which was found by Byers et al. [38] to be more effective than spray cleaning in removing VRE from hospital room surfaces. The goal of the Byers investigation [38] was to eradicate VRE from the environment. Our study realized significant reductions in patient acquisition of VRE colonization despite persistent low-level environmental contamination. This suggests that there may be a threshold level of VRE contamination that is important in maintaining a high rate of cross-transmission.

Our study has limitations. The physical layout of our MICU did not permit random assignment of the intervention. Therefore, we used a pre- and postintervention study design. Although we measured numerous patient and population variables during the sequential study periods, we might not have identified all potential confounders. Colonization pressure was not considered to be a confounder, because it is dependent in part on patient acquisition of VRE. Finally, we studied only VRE, so the applicability of our findings to other antibiotic-resistant nosocomial pathogens with potentially significant environmental reservoirs, such as methicillin-resistant *Staphylococcus aureus* [9], is unknown.

The success and relative ease of institution and maintenance of the environmental cleaning intervention contrasts sharply with the failure of our hand hygiene intervention. The difference may be due in part to the fact that the sole task of housekeepers was to clean patient rooms, whereas health care workers were tasked to clean their hands among myriad competing responsibilities. Furthermore, the housekeeping intervention required changing the behavior of only 7 housekeepers, whereas success of the hand hygiene improvement campaign would have required the cooperation of hundreds of health care workers.

Adherence to hand disinfection did improve early in the environmental cleaning period, perhaps as a Hawthorne effect related to our presence in the MICU, but decreased subsequently, despite our continued presence. During the hand hygiene improvement intervention period, adherence rates returned to baseline levels but never exceeded them. Despite only modest rates of adherence with hand hygiene, health care worker hand contamination decreased significantly during the environmental cleaning intervention period and remained low for the duration of the study. The difficulty in achieving adequate hand hygiene adherence, especially in settings with high workloads and demand for hand disinfection, such as intensive care units, is well described [39, 40]. Because most nosocomial pathogens are transmitted via contaminated health care worker hands, it is essential that clean hands be a central goal of all infection-control programs. Given the challenges to ensuring adequate adherence to hand hygiene, we believe that adjunctive measures, such as improving environmental cleaning, are worth exploring. Decreasing environmental contamination may be an important addition to more-traditional efforts to decrease the spread of some antibiotic-resistant pathogens within hospitals.

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Potential conflicts of interest. All authors: no conflicts.

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