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Risk of Acquiring Antibiotic-Resistant Bacteria From Prior Room Occupants

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Background: Environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and vancomycin-resistant enterococci (VRE) occurs during the care of patients harboring these organisms and may increase the risk of transmission to subsequent room occupants.

Methods: Twenty-month retrospective cohort study of patients admitted to 8 intensive care units performing routine admission and weekly screening for MRSA and VRE. We assessed the relative odds of acquisition among patients admitted to rooms in which the most recent occupants were MRSA positive or VRE positive, compared with patients admitted to other rooms.

Results: Of 11 528 intensive care unit room stays, 10 151 occupants were eligible to acquire MRSA, and 10 349 were eligible to acquire VRE. Among patients whose prior room occupant was MRSA positive, 3.9% acquired MRSA, compared with 2.9% of patients whose prior room occupant was MRSA negative (adjusted odds ratio, 1.4; $P = .04$). VRE, Among patients whose prior room occupant was VRE positive, these values were 4.5% and 2.8% respectively (adjusted odds ratio, 1.4; $P = .02$). These excess risks accounted for 5.1% of all incident MRSA cases and 6.8% of all incident VRE cases, with a population attributable risk among exposed patients of less than 2% for either organism. Acquisition was significantly associated with longer post–intensive care unit length of stay.

Conclusions: Admission to a room previously occupied by an MRSA-positive patient or a VRE-positive patient significantly increased the odds of acquisition for MRSA and VRE. However, this route of transmission was a minor contributor to overall transmission. The effect of current cleaning practices in reducing the risk to the observed levels and the potential for further reduction are unknown.

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METHICILLIN-RESISTANT *Staphylococcus aureus* (MRSA) and vancomycin-resistant enterococci (VRE) are antibiotic-resistant pathogens responsible for substantial morbidity and mortality in hospitals.[1-8] Patients acquiring MRSA or VRE are at significant risk of subsequent invasive disease. Our research group previously found that 29% of new carriers developed invasive sequelae within 18 months.[9] Half of these events occurred after discharge from the hospital. The risk of MRSA sequelae among intensive care unit (ICU) patients is even greater, with risks of bacteremia as high as 38%.[7] Similarly, 19% of ICU patients colonized with VRE develop subsequent infection during the same hospitalization.[10]

Given these risks, prevention of transmission has become increasingly important.[11] Implicated sources of transmission include patients,[12-15] health care workers,[16-19] and environmental contamination.[20-24] Many objects are persistently contaminated, including floors, beds, gowns, tables, faucets, doorknobs, blood pressure cuffs, and computer terminals,[20-24] even after terminal cleaning.[25,26]

Although environmental contamination has been well documented, quantifying the attributable risk of transmission to subsequent occupants is challenging. This risk presumably depends on whether contamination exceeds the threshold for transmission and whether cleaning practices decontaminate below this threshold. Transmission via inanimate sources may be highest in ICUs because of comorbidities and the intensity of medical care. A previous study[26] performed a 4-day cross-sectional survey of ICU rooms following terminal cleaning and found that 1 of every 2 rooms with contaminated items was associated with VRE acquisition during a 9-month period. Although high-risk rooms may exist because of difficult-to-clean design or poor placement of hand hygiene equipment, transmission may be more directly linked to a prior occupant who harbors a resistant organism rather than to a particular room. We evaluated whether admission to an ICU room previously occu-

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Table 1. Discharge Cleaning Standards for Hospital Rooms of Patients Placed on Contact Precautions*

Cleaning Surface	Protocol†
Dusting of room	Includes use of high dusting tool
Spot cleaning of walls	Limited to high-touch and visibly soiled areas‡
Bedside tables and carts	All surfaces wiped, including inside drawers
Bed	Linen removed; wiping of frame, all mattress sides, rails, skirts, wheels, pillow
Bed curtains	Replaced
Closet, chairs, and floor lamps	All surfaces wiped
Hand controls	Wiping of bed controls, telephone, television control, all cords
Patient care equipment	Wiping of poles, monitors, blood pressure cuffs, dedicated stethoscopes, etc
Bathroom	Surfaces and fixtures wiped; toilet sanitized; toilet mop replaced in ICUs only§
Waste receptacles	Wiped and relined
Bed linen	Clean linen placed
Floor	Mopped; mops changed daily or when visibly soiled

*Representative descriptions of the detailed protocol are provided.
†All cleaning performed using a quaternary ammonium agent.
‡High-touch surfaces with frequent hand contact, such as doorknobs and light switches.
§In non–intensive care units (ICUs), mop container is cleaned and refilled with germicidal solution.

pied by an MRSA carrier or a VRE carrier increased a patient's risk of acquiring these pathogens.

METHODS

We conducted a retrospective cohort study of patients admitted to 8 adult ICUs at a tertiary care hospital between September 1, 2003, and April 30, 2005. All ICUs had a 10-bed capacity and included medical, cardiac, general surgery, burn/trauma, cardiac surgery (2 units), thoracic surgery, and neurosurgery units. Admission and weekly surveillance nares cultures for MRSA and rectal cultures for VRE were obtained in all ICUs, providing a systematic method to distinguish between imported and incident cases during endemic conditions. This study was approved by the institutional review board at Brigham and Women's Hospital.

Samples were collected using Dacron swabs and were transported to the hospital microbiology laboratory. Cultures for MRSA were plated on blood agar, followed by *S aureus* identification and confirmation of methicillin resistance using Mueller-Hinton plates with oxacillin disks. Cultures for VRE were plated on bile esculin azide agar with 6 µg of vancomycin per milliliter. All identification and susceptibility cut points were in accord with Clinical and Laboratory Standards Institute guidelines.[27]

Table 1 summarizes the Brigham and Women's Hospital discharge cleaning procedures for rooms of patients placed on contact precautions. Representative descriptions of the detailed protocol are provided. On average, discharge cleaning of a contact precautions room takes 35 to 37 minutes, compared with 30 minutes for a non–contact precautions room. The only difference in the cleaning protocol between contact precautions vs non–contact precautions rooms is the replacement of the bed curtains.

Data collection and analyses were performed identically for MRSA and VRE. We obtained ICU census information detailing the occupants and dates of occupancy during the study period. For each occupant, we collected age, sex, and hospital *International Classification of Diseases, Ninth Revision* codes within 1 year of ICU admission. We also collected each occupant's hospital admission date, total hospital length of stay (LOS), pre-ICU LOS, ICU LOS, post-ICU LOS, duration of room vacancy before admission, and MRSA and VRE status (carrier vs noncarrier) at room admission and discharge. Among those who acquired MRSA or VRE, we recorded the hospital day and ICU day of acquisition. We also collected information on the prior room occupant, including occupancy dates, room LOS, and MRSA and VRE status at room discharge.

History of MRSA or VRE carriage (colonization and infection) was obtained from infection control records. These records are based on microbiology laboratory results, reports of MRSA and VRE from outside facilities, and (rarely) patient self-reports. We also collected the dates of all institutional cultures positive for MRSA or VRE and the dates and results of surveillance cultures (positive and negative).

Patients were eligible to acquire MRSA and VRE during an ICU stay if they had no known history of MRSA or VRE before room admission. Patients were excluded if a surveillance or clinical culture was positive for MRSA or VRE within 2 calendar days of ICU admission, in accord with definitions for attributable hospital-associated acquisition from the Centers for Disease Control and Prevention.[28] Patients could contribute to any number of ICU room stays until acquisition occurred.

We calculated the number of ICU room stays that represented a potential for MRSA or VRE transmission. We then assessed the frequency at which an eligible patient was exposed to a room in which the prior occupant was an MRSA carrier or a VRE carrier. The proportions of patients acquiring MRSA and VRE were assessed by exposure status, and crude odds ratios (using the Mantel-Haenszel test) were calculated.

We assessed potential differences in comorbidities between the exposed and unexposed groups. We evaluated 6 a priori comorbidities, assigned based on corresponding *International Classification of Diseases, Ninth Revision* codes within 1 year of ICU admission, including the day of admission. Because ICUs differ substantially in their patient populations, we calculated the percentage of patients with each comorbidity, stratified by exposure status and ICU. To estimate the magnitude potential confounding, we used generalized linear mixed models[29] to measure the association between comorbidities and prior occupant status, while adjusting for clustering by unit.

To assess the association between prior room occupant status and MRSA and VRE acquisition, while controlling for demographic, comorbidity, and LOS variables, we performed additional generalized linear mixed models that accounted for clustering within ICUs. Covariates included age, sex, hospital LOS before ICU admission, prior occupant LOS, and duration of room vacancy before occupancy, as well as diagnoses of diabetes mellitus, end-stage renal disease, end-stage liver disease, noncancer immunocompromised state, hematologic malignancies, and nonhematologic malignancies. Backward selection models were run using SAS version 9.1 (SAS Institute, Cary NC), and variables were retained at $\alpha = .05$. Interactions were assessed and retained at $\alpha = .05$.

In addition, we calculated the excess risks and population attributable risks (etiologic fractions) of MRSA and VRE acquisition associated with a prior occupant's MRSA and VRE status.[30-32] Excess risk was calculated as the difference between acquisition risk in patients whose prior room occupant was a carrier of MRSA or VRE vs a noncarrier. Population attributable risk was calculated for the exposed population as the num-

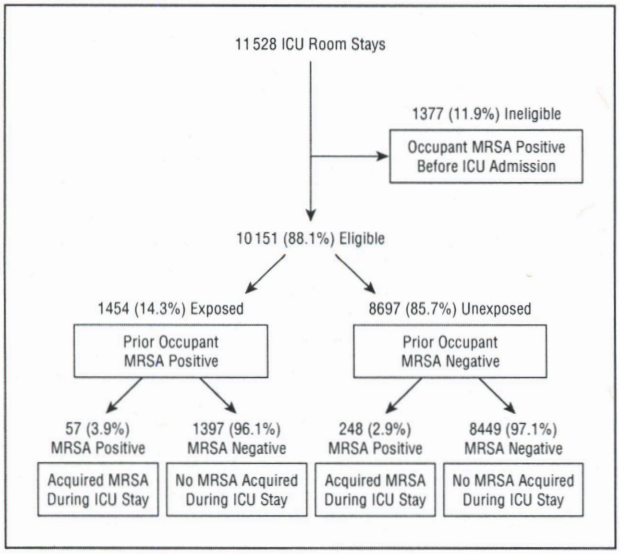

Figure 1. Study schematic of the number of intensive care unit (ICU) room occupants during the 20-month study period and their risk of methicillin-resistant *Staphylococcus aureus* (MRSA) acquisition according to the MRSA status of the prior room occupant. Patients may be represented more than once because of multiple ICU admissions.

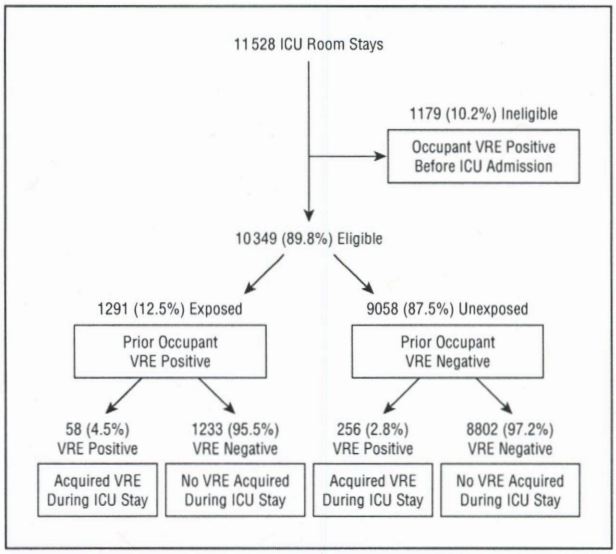

Figure 2. Study schematic of the number of intensive care (ICU) room occupants during the 20-month study period and their risk of vancomycin-resistant enterococci (VRE) acquisition according to the VRE status of the prior room occupant. Patients may be represented more than once because of multiple ICU admissions.

ber of cases per 100 patients that would have been prevented had prior occupant carriage been eliminated as a source.

Last, we compared the mean pre-ICU, ICU, and post-ICU LOS among patients who acquired MRSA or VRE and patients who did not, using 2-tailed *t* tests. We used generalized linear mixed models to further assess whether MRSA or VRE acquisition was associated with a post-ICU LOS of 10 days or longer when accounting for clustering by unit and adjusting for age, sex, pre-ICU LOS, ICU LOS, prior occupant status, and comorbidities.

RESULTS

A total of 8203 patients had 11 528 ICU room stays. Among them, 809 patients (1377 ICU room stays) were MRSA carriers on ICU admission, leaving 7629 patients (10 151 ICU room stays) eligible for MRSA acquisition. For VRE, 658 patients (1179 ICU room stays) were VRE carriers on ICU admission, leaving 7806 patients (10 349 ICU room stays) eligible for VRE acquisition. Descriptive characteristics were identical in both cohorts. The mean age was 61 years, and 58% were male. In both cohorts, eligible occupants were admitted to an ICU a median of 0 days after hospital admission and had a median ICU room LOS of 3 days.

The results for MRSA transmission are shown in **Figure 1**. Fourteen percent of ICU bed occupants had a prior occupant who was MRSA positive. Patients assigned to a room previously occupied by an MRSA carrier vs a noncarrier had a significantly higher risk of MRSA acquisition (3.9% vs 2.9%, $P=.03$). The crude odds ratio of MRSA acquisition was 1.4 (95% confidence interval, 1.0-1.9). This 1.0% excess risk represented 5.1% (15.5/305) of all ICU MRSA acquisition during the study period and translated to a 1.1% (15.5/1454) population attributable risk among the exposed, or 1 in 94 exposed room stays.

The results for VRE transmission are shown in **Figure 2**. Thirteen percent of ICU bed occupants had a prior occupant who was VRE positive. Patients assigned to a room previously occupied by a VRE carrier vs a noncarrier had a significantly higher risk of VRE acquisition (4.5% vs 2.8%, $P=.001$). The crude odds ratio of VRE acquisition was 1.6 (95% confidence interval, 1.2-2.2). This 1.8% (difference due to rounding) excess risk represented 6.8% (21.5/314) of all ICU VRE acquisition during the study period and translated to a 1.7% (21.5/1291) population attributable risk among the exposed, or 1 in 59 exposed room stays.

Among those who acquired MRSA, 95% had an ICU admission nares culture indicating a negative carrier status for MRSA. Among those who acquired VRE, 91% had an ICU admission rectal culture indicating a negative carrier status for VRE. The compliance with admission and weekly nares and rectal swabs was 88% across all ICUs. Restricting these data to patients with negative admission nares or rectal cultures did not alter the results.

Although variable across ICUs, comorbidities were not significantly different between exposed and unexposed groups when accounting for clustering by ICU (**Table 2**). In addition, among those who were newly detected to harbor MRSA, the time until MRSA detection was similar between patients exposed to a prior occupant who was a carrier (median, ICU day 7) vs a noncarrier (median, ICU day 7). Similarly, there was no significant difference in the hospital day of VRE acquisition between those exposed to a VRE-positive prior occupant (median, ICU day 7) or a VRE-negative prior occupant (median, ICU day 8). These results reflect our hospital's protocols regarding clinical culture data and the timing of weekly postadmission surveillance cultures.

In the main multivariate analyses adjusting for clustering by ICU, exposure to a prior occupant harboring MRSA or VRE remained a significant predictor of subsequent acquisition when controlling for other variables such as age, sex, comorbidities, pre-ICU LOS, prior

Table 2. Association Between Comorbidities and Prior Occupant Status, Accounting for Clustering by Intensive Care Unit (ICU)

Comorbidity	Prior Occupant Status*		Odds Ratio (95% Confidence Interval)	*P* Value
	Positive	Negative		
Methicillin-Resistant *Staphylococcus aureus*				
Diabetes mellitus	12.5-36.0	12.6-37.9	1.1 (0.9-1.2)	.41
End-stage renal disease	1.8-13.8	1.5-11.2	1.0 (0.8-1.3)	.99
End-stage liver disease	1.4-5.9	0.5-5.2	1.2 (0.9-1.7)	.24
Immunocompromised, noncancer	1.8-20.1	2.0-19.3	1.0 (0.8-1.3)	.86
Hematologic malignancy	0.9-18.9	0.8-15.6	1.0 (0.8-1.3)	.77
Solid cancer	5.5-72.7	5.0-73.9	1.1 (0.9-1.2)	.49
Vancomycin-Resistant Enterococci				
Diabetes mellitus	9.7-41.2	12.7-37.4	1.1 (1.0-1.3)	.15
End-stage renal disease	1.5-11.8	1.4-11.1	1.1 (0.9-1.4)	.35
End-stage liver disease	0.9-4.7	0.1-4.7	0.9 (0.6-1.4)	.79
Immunocompromised, noncancer	1.0-17.2	1.9-13.7	1.2 (0.9-1.5)	.18
Hematologic malignancy	0.0-15.1	0.8-14.0	1.0 (0.8-1.3)	.92
Solid cancer	8.7-67.8	4.7-75.0	0.9 (0.8-1.1)	.24

*Range of percentage comorbidity among patients across the 8 ICUs.

Table 3. Predictors of Methicillin-Resistant *Staphylococcus aureus* (MRSA) and Vancomycin-Resistant Enterococci (VRE) Acquisition*

Model	Odds Ratio (95% Confidence Interval)	*P* Value
MRSA		
Prior occupant MRSA positive	1.4 (1.0-1.8)	.04
Age, in decades	1.1 (1.0-1.2)	.02
Pre-ICU LOS†	1.2 (1.1-1.4)	<.001
Leukemia	0.4 (0.2-0.9)	.02
VRE		
Prior occupant VRE positive	1.4 (1.0-1.9)	.02
Age, in decades	1.2 (1.1-1.3)	<.001
Pre-ICU LOS†	1.4 (1.3-1.6)	<.001
Diabetes mellitus	1.3 (1.0-1.7)	.03

Abbreviations: ICU, intensive care unit; LOS, length of stay.
*No interactions found.
†By 10-day intervals.

occupant LOS, and duration of room vacancy before occupancy (**Table 3**). The adjusted odds ratios for MRSA and VRE acquisition were identical to the crude odds ratios. There was minimal change in population attributable risk for MRSA or VRE when using adjusted odds ratios to estimate risk.

In keeping with Centers for Disease Control and Prevention guidelines,[28] our main analysis excluded patients who were known to be MRSA or VRE carriers before admission, as well as patients who were newly detected carriers within 2 calendar days of a room stay. Nevertheless, because transmission could have occurred during the initial 48 hours of room occupancy, we assessed whether newly detected acquisition within 2 calendar days of admission differentially occurred based on prior occupant status. We found similar results between patients whose prior room occupant was an MRSA carrier (4.9% [75/1529]) vs a noncarrier (4.4% [401/9098]) (P=.34). In contrast, new detection of VRE during the first 2 calendar days of an ICU stay was higher among patients whose prior room occupant was a VRE carrier (5.6% [77/1368]) vs a noncarrier (4.1% [385/9445]) (P=.008).

We further compared LOS data between occupants who newly acquired MRSA and those who did not (**Table 4**). Patients who acquired MRSA had a significantly longer hospital LOS. However, this was because of longer pre-ICU (before MRSA detection) LOS, in addition to longer ICU, and post-ICU LOS. Similar results were found for VRE (**Table 5**). In a multivariate models, acquisition of MRSA and VRE was associated with prolonged post-ICU LOS even when controlling for pre-ICU LOS, ICU LOS, and comorbidities (**Table 6**).

We also compared LOS data between occupants who newly acquired MRSA and those who already harbored MRSA at ICU admission. The ICU LOS was substantially longer among occupants who newly acquired MRSA (mean, 18.8 vs 7.0 days; P<.001). Similarly, the ICU LOS was longer among occupants who newly acquired VRE, compared with those who already harbored VRE at ICU admission (mean, 18.2 vs 7.7 days; P<.001). However, there were no significant differences in the post-ICU LOS between patients with newly acquired or previously acquired MRSA (mean, 12.8 vs 13.7 days; P=.5) or VRE (mean, 12.4 vs 13.1 days; P=.6). Patients who newly acquired MRSA or VRE and patients who harbored MRSA or VRE on admission had ICU LOS and post-ICU LOS that were significantly longer than the corresponding LOS among noncarriers. Among patients already known to harbor MRSA or VRE at ICU admission, the median time since initial detection was 52 days (range, 1-5406 days) for MRSA and 40 days (range, 1-3845 days) for VRE.

COMMENT

Admission to an ICU room previously occupied by an MRSA-positive patient or a VRE-positive patient was significantly associated with an elevated risk of acquiring MRSA or VRE, respectively. However, this increased risk

Table 4. Description of ICU Room Occupants by MRSA Acquisition and by MRSA Status of Prior Occupant

Descriptor	Exposed MRSA Positive	Unexposed MRSA Positive	Exposed MRSA Negative	Unexposed MRSA Negative	All MRSA Positive	All MRSA Negative
Unique patients	57	248	1311	6632	305	7430*
Room stays	57	248	1397	8449	305	9846
Male occupants, %	57.9	57.7	58.9	57.7	57.7	57.8
Occupant age, mean, y	60.8	63.1	59.9	60.9	62.6	60.8
LOS, mean (median), d						
Hospital	38.1 (31)	34.8 (27)	13.5 (9)	13.4 (9)	35.4 (27)	13.4 (9)†
Pre-ICU	3.9 (1)	3.8 (1)	2.4 (0)	2.4 (0)	3.8 (1)	2.4 (0)†
ICU	21.1 (15)	18.3 (14)	4.0 (2)	3.9 (3)	18.8 (15)	3.9 (3)†
Post-ICU	13.1 (6)	12.7 (7)	7.1 (4)	7.1 (4)	12.8 (7)	7.1 (4)†
Prior room occupant	8.2 (3)	3.8 (2)‡	9.0 (4)	3.9 (3)†	4.6 (3)	4.6 (3)
Lag between room occupants, mean (median), d	0.5 (0)	0.5 (0)	0.6 (0)	0.6 (0)	0.5 (0)	0.6 (0)

Abbreviations: ICU, intensive care unit; LOS, length of stay; MRSA, methicillin-resistant *Staphylococcus aureus*.
*Does not equal the sum of exposed and unexposed MRSA-negative patients, as patients may be represented in both groups because of multiple ICU admissions.
†$P<.001$ comparing means with the adjacent cell (left) using t tests.
‡$P<.01$ comparing means with the adjacent cell (left) using t tests.

Table 5. Description of ICU Room Occupants by VRE Acquisition and by VRE Status of Prior Occupant

Descriptor	Exposed VRE Positive	Unexposed VRE Positive	Exposed VRE Negative	Unexposed VRE Negative	AI VRE Positive	AI VRE Negative
Unique patients	58	256	1157	6904	314	7626*
Room stays	58	256	1233	8802	314	10035
Male occupants, %	62.1	62.5	59.0	57.4	62.4	57.6
Occupant age, mean, y	63.2	65.9	61.0	61.0	65.4	60.9
LOS, mean (median), d						
Hospital	31.8 (25.5)	36.7 (28.5)	13.7 (9)	13.3 (9)	35.8 (28)	13.3 (9)†
Pre-ICU	3.7 (1)	5.6 (2)	2.5 (0)	2.2 (0)	5.2 (1)	2.3 (0)†
ICU	17.8 (12)	18.3 (12.5)	4.1 (3)	3.9 (2)	18.2 (12.5)	3.9 (3)†
Post-ICU	10.3 (5.5)	12.8 (7)	7.1 (4)	7.2 (4)	12.4 (7)	7.1 (4)†
Prior room occupant	9.1 (5)	4.0 (2)‡	9.6 (5)	4.0 (3)†	4.9 (3)	4.7 (3)
Lag between room occupants, mean (median), d	0.4 (0)	0.7 (0)	0.6 (0)	0.6 (0)	0.6 (0)	0.6 (0)

Abbreviations: ICU, intensive care unit; LOS, length of stay; VRE, vancomycin-resistant enterococci.
*Does not equal the sum of exposed and unexposed MRSA-negative patients, as patients may be represented in both groups because of multiple ICU admissions.
†$P<.001$ comparing means with the adjacent cell (left) using t tests.
‡$P = .001$ comparing means with the adjacent cell (left) using t tests.

accounted for less than 10% of all cases of ICU acquisition, with a population attributable risk of less than 2% among those exposed.

This excess risk occurred despite our hospital's room cleaning procedures at discharge, which exceed the Centers for Disease Control and Prevention and Healthcare Infection Control Practices Advisory Committee 2003 national guideline.[33] Procedures performed in addition to national standards included the replacement of the bed curtains in contact precautions rooms and the use of pour bottles instead of spray bottles for the dispensing of cleaning solutions. The use of pour bottles was implemented to prevent aerosolization of chemical agents and results in the use of larger quantities of cleaning agent. In addition, all environmental services aides underwent hands-on training in cleaning protocols, with twice-monthly quality control assessments in which compensation is tied to the mean scores for each fiscal year. It is impossible to know the extent to which current national standards or additional practices in our hospital reduced the risk of transmission to the low level we observed.

The 40% increased odds of transmission associated with a prior occupant's carriage of MRSA or VRE suggests that national recommendations for terminal room cleaning do not completely prevent transmission. This is consistent with published evidence of the environmental contamination of room surfaces and equipment with MRSA and VRE[20-24,34] and the lack of full eradication by standard cleaning procedures.[25,26,35] Nevertheless, the low population attributable risk among the exposed patients suggests that levels of contamination do not pose a high risk for transmission or that current cleaning methods generally reduce contamination below levels required for transmission. Based on our findings, the prevention of 1 case of acquisition due to room contami-

Table 6. Predictors of Prolonged (>10 Days) Post–Intensive Care Unit (ICU) Length of Stay (LOS)

Predictor	Odds Ratio (95% Confidence Interval)	*P* Value
Male sex	1.2 (1.1-1.4)	<.001
Age, in decades	1.1 (1.1-1.1)	<.001
Methicillin-resistant *Staphylococcus aureus* acquisition	1.8 (1.3-2.4)	<.001
Vancomycin-resistant enterococci acquisition	1.4 (1.0-2.0)	.04
Pre-ICU LOS*	1.8 (1.6-2.0)	<.001
ICU LOS*	1.2 (1.1-1.3)	<.001
End-stage renal disease	1.6 (1.3-2.0)	<.001
Immunocompromised, noncancer	1.6 (1.3-2.1)	<.001

*By 10-day intervals.

nation could require more intensive cleaning of 94 rooms vacated by MRSA carriers and of 59 rooms vacated by VRE carriers.

This risk of transmission attributable to residual environmental contamination that persists despite terminal cleaning of patient rooms may not be applicable to heavily trafficked common areas, such as procedure rooms, hallways, physician work areas, and nursing stations. Transmission due to contamination in these areas may be more dependent on medical staff as intermediary carriers, whereas transmission due to prior occupants may arise from direct patient contact with the environment.

Other predictors of acquisition included older patient age and longer pre-ICU LOS. In addition, having diabetes mellitus was predictive of VRE acquisition, while having leukemia was negatively associated with MRSA acquisition. The finding of reduced acquisition among patients with acute leukemia may be related to the heightened vigilance in hand washing and infection control surrounding these patients during hospitalization. None of these variables were differentially associated with prior occupant status.

We also found that ICU patients newly detected as harboring these organisms had a significantly longer ICU LOS than those already known to be carrying MRSA or VRE, perhaps because recent acquisition confers a high infection risk. Acquisition of MRSA and VRE leads to a 15% to 40% risk of infection within the same hospital stay as initial detection,[7,9,10] and that infection increases LOS.[3,36,37] However, we emphasize the importance of evaluating subcomponents of LOS (preacquisition and postacquisition) and controlling for preacquisition differences that may otherwise account for increased postacquisition LOS. Not only were ICU LOS and post-ICU LOS significantly longer among patients newly detected as harboring MRSA or VRE, compared with those who remained negative, but pre-ICU LOS was also significantly longer. Patients acquiring these organisms may have specific characteristics that predispose them to prolonged hospital LOS. Nevertheless, when controlling for pre-ICU LOS and comorbidities, MRSA acquisition was still associated with an 80% increase in post-ICU LOS, independent of the 40% increase associated with VRE acquisition.

Limitations of this study include the fact that incidence may be somewhat underestimated because surveillance cultures were only performed on admission and weekly. It is possible that additional cases of transmission occurred that were undetected by clinical and surveillance cultures performed during the ICU room stay. We also did not evaluate the potential effect of transmission due to other known risk factors[12,14] for MRSA and VRE acquisition such as medical devices,[38,39] antibiotic use,[14,33,40,41] medical personnel, or other comorbidities unassessed in this study. Nevertheless, our results would not be affected unless such factors were differentially distributed in both MRSA and VRE study populations based on whether the prior room occupant was a carrier or a noncarrier. We find this to be unlikely as bed and nursing assignments are made without knowledge of the prior occupant's MRSA or VRE status. In addition, our institution does not cohort patients or staff during the care of MRSA and VRE carriers, all of whom occupy single rooms. Another limitation is that we did not perform environmental sampling and are unable to comment on the level of residual contamination under which transmission occurred. Finally, our findings may not be generalizable to other hospitals or non-ICU settings because of differences in patient populations or terminal room cleaning methods.

CONCLUSIONS

We found a 40% increased odds of transmission of MRSA and VRE attributable to the carrier status of prior room occupants, strongly suggesting a role for environmental contamination, despite room cleaning methods that exceeded national standards. This increased risk accounted for a small fraction of the total cases of acquired MRSA or VRE in these ICUs. However, this small fraction could account for a substantial number of transmission events if the prevalence of these organisms continues to rise. Additional data are needed to determine whether more intensive cleaning practices can reduce the risk further and, if so, whether this is worthwhile in a resource-limited system.

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Author Contributions: Dr Huang had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. *Study concept and design:* Huang and Platt. *Acquisition of data:* Huang and Datta. *Analysis and interpretation of data:* Huang, Datta, and Platt. *Drafting of the manuscript:* Huang. *Critical revision of the manuscript for important intellectual content:* Datta and Platt. *Statistical analysis:* Huang. *Obtained funding:* Huang and Platt. *Administrative, technical, and material support:* Huang and Datta. *Study supervision:* Huang and Platt.
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