ORIGINAL ARTICLE

Association Between Healthcare-Associated Infection and Exposure to Hospital Roommates and Previous Bed Occupants with the Same Organism

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OBJECTIVE. To quantify the association between having a prior bed occupant or roommate with a positive blood, respiratory, urine, or wound culture and subsequent infection with the same organism.

DESIGN. Case-control study.

SETTING. The study included 4 hospitals within an academically affiliated network in New York City, including a community hospital (221 beds), a pediatric acute-care hospital (283 beds), an adult tertiary-/quaternary-care hospital (647 beds), and a pediatric and adult tertiary-/quaternary-care hospital (914 beds).

PATIENTS. All 761,426 inpatients discharged from 2006 to 2012 were eligible. Cases included all patients who developed a healthcare-associated infection (HAI) with *Staphylococcus aureus, Acinetobacter baumannii*, *Streptococcus pneumoniae*, *Pseudomonas aeruginosa, Klebsiella pneumoniae*, *Enterococcus faecalis*, or *Enterococcus faecium*. Controls were uninfected patients matched by fiscal quarter, hospital, and length of stay. For each bed occupied during the 3–5-day period prior to infection, microbiology results for assigned roommates and the patient who occupied the bed immediately prior to the case were collected. For controls, the day of infection of the matched case served as the reference point.

RESULTS. In total, 10,289 HAIs were identified. In a multivariable analysis controlling for both exposures and patient characteristics, the odds of cases having been exposed to a prior bed occupant with the same organism were 5.83 times that of controls (95% confidence interval [CI], 3.62–9.39), and the odds of cases having been exposed to a roommate with the same organism were 4.82 times that of controls (95% CI, 3.67–6.34).

CONCLUSION. Infected or colonized roommates and prior occupants do pose a risk, which may warrant enhanced terminal and intermittent cleaning measures.

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More than 700,000 healthcare-associated infections (HAIs) occur in US hospitals each year.[1] These infections, considered to be largely preventable, accrue $28–45 billion annually in excess healthcare costs and are fatal in nearly 6% of cases.[2–4] Efforts to improve quality of care while reducing costs have made HAI prevention a national priority and have sparked a surge of innovative measures aimed at curtailing their spread.[5,6] Many of these interventions have specifically targeted high-risk patients with protocols for the care and maintenance of indwelling devices, with measurable but varied success.[7]

Meanwhile, a growing body of evidence demonstrating widespread contamination of hospital rooms and equipment has led to increasing concern about the risks posed to all patients by current cleanliness standards and practices.[8] Numerous products are being developed and marketed to hospitals for the purpose of improving environmental disinfection, with particular attention given to routine cleaning for patients with multidrug-resistant organisms and terminal cleaning after discharge.[9] However, very few studies have actually examined whether there is a link between contamination in patient rooms and risk of infection. Given the constraints of financial and human resources for infection prevention and control, it is important to quantify the potential impact of enhanced environmental cleanliness. Our study addressed this question by evaluating whether there is an association between HAIs and exposure to infected or colonized hospital roommates or prior room occupants using 7 years of data from 4 inpatient acute-care hospitals.

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METHODS

Sample and Setting

This study was conducted in 4 inpatient hospitals in New York City. The hospitals, all part of the same healthcare network, included a community hospital (221 beds), a pediatric acute-care hospital (283 beds), an adult tertiary-/quaternary-care hospital (647 beds), and a pediatric and adult tertiary-/quaternary-care hospital (914 beds). All patients discharged between January 1, 2006, and December 31, 2012, were eligible for inclusion. This study was reviewed and approved by the institutional review boards of the study facilities, and waivers of informed consent were granted.

Data Collection

All study data were collected retrospectively. Data were sourced from multiple electronic systems used for clinical documentation and administrative purposes throughout the hospital network and were linked using unique medical record numbers and dates of admission and discharge.[10] Demographic information and patient characteristics were sourced from administrative data and included age, sex, risk of mortality as measured by the Charlson comorbidity index, and specific comorbid conditions including malignancies, renal failure, and diabetes. *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) codes were used to create the Charlson comorbidity index and to identify comorbid conditions. Patient room and bed assignments for each day of hospitalization were collected from the admission–discharge–transfer system. Culture results and antibiogram data including date and site of culture collection were obtained from clinical microbiology records.

Study Design

A matched case-control design was used to evaluate the association between having a prior bed occupant or roommate with a positive blood, respiratory, urine, or wound culture and subsequent infection with the same organism and comparable antibiotic sensitivity profile. These infections were chosen because they are some of the most common HAIs occurring in inpatient settings, because they are reliably identifiable in electronic records, and because patients can develop such infections through contact with contaminated hands or surfaces. Cases included all patients who developed a hospital-acquired bloodstream infection, urinary tract infection, surgical site infection, or pneumonia with 1 of the following organisms: oxacillin-sensitive *Staphylococcus aureus,* oxacillin-resistant *S. aureus,* ampicillin-sulbactam-sensitive *Acinetobacter baumannii,* ampicillin-sulbactam-resistant *A. baumannii,* penicillin-sensitive *Streptococcus pneumonia,* penicillin-resistant *S. pneumonia,* levofloxacin-sensitive *Pseudomonas aeruginosa,* levofloxacin-resistant *P. aeruginosa,* imipenem-sensitive *Klebsiella pneumoniae,* imipenem-resistant *Klebsiella pneumoniae,* vancomycin-sensitive *Enterococcus faecalis* and *E. faecium* and vancomycin-resistant *E. faecalis* and *E. faecium*. These organisms were chosen to represent a broad range of pathogens commonly seen in inpatient settings with various modes of transmission, preferential body sites of infection, and differing viability on healthcare surfaces. HAIs were detected via electronic algorithms analogous to the Centers for Disease Control and Prevention National Healthcare Safety Network surveillance definitions (Figure 1).[10,11]

Controls were matched to cases in a 1:1 ratio and were randomly selected from all patients who (1) never had a positive culture with the organism under investigation during

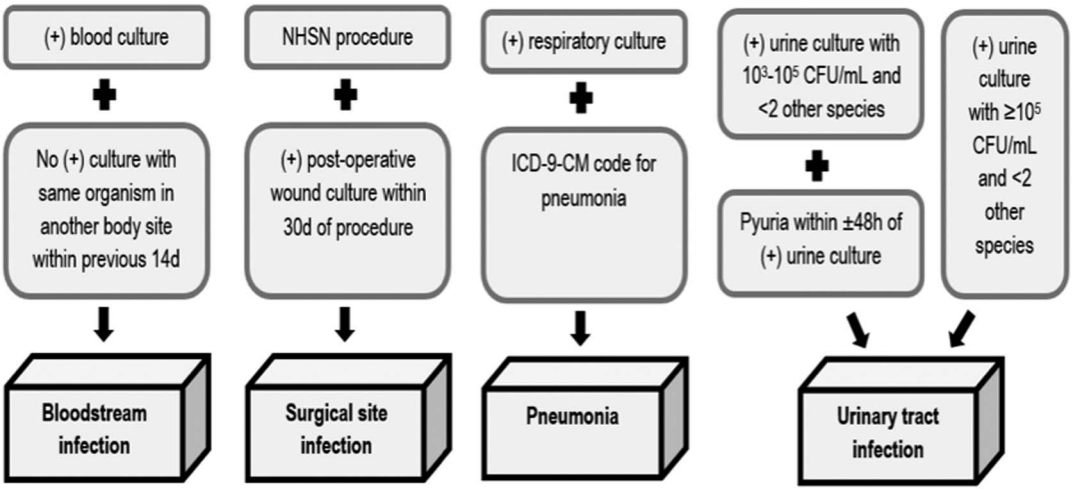

FIGURE 1. Electronic algorithms used to identify healthcare-associated infections based on the Centers for Disease Control and Prevention National Healthcare Safety Network surveillance guidelines.[10,11] Data from the institutions' clinical microbiology laboratories were used in conjunction with *International Classification of Diseases, Ninth Revision, Clinical Modification* (ICD-9-CM) diagnosis and procedure codes.

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their hospitalization, (2) were admitted during the same fiscal quarter as the case, (3) were admitted to the same hospital as the case, and (4) had a length of stay at least as long as the case's length of stay prior to infection.

Exposures

Exposure to prior bed occupant. All beds that each case occupied during the 3–5-day period prior to infection were identified using a computerized algorithm. For each of these beds, a second algorithm was applied to identify the patient who occupied the bed immediately prior to the case. A third algorithm searched the clinical microbiology data to determine whether any of the previous occupants had a positive culture with the organism of interest at any point prior to being discharged from the bed they occupied prior to the case. The same process was applied for controls, with the matched case's day of infection serving as the reference point. For example, if the matched case had an infection on day 10, we looked back 3–5 days from day 10 of the control's hospital stay.

Exposure to hospital roommate. All rooms that each case occupied during the 3–5-day period prior to infection were identified using a computerized algorithm. For each of these rooms, a second algorithm was applied to identify any other patients assigned on the same date(s) as the case. A third algorithm searched the clinical microbiology data to determine whether any of the roommates had a positive culture with the organism of interest at any point prior to sharing a room with the case. The same process was applied for controls, with the matched case's day of infection serving as the reference point.

Data Analysis

Bivariate comparisons between cases and controls with respect to exposure to infected or colonized prior room occupants, exposure to infected or colonized roommates, age, Charlson comorbidity index, sex, presence of malignancies, renal failure, and diabetes mellitus were conducted within each organism category using the χ^2 test for independence, the Fisher exact test, or the 2-sample *t* test, as appropriate. The overall numbers and proportions of cases and controls exposed to infected or colonized prior room occupants and roommates were tabulated to determine crude odds ratios (OR) and 95% confidence intervals (CI). Multivariable logistic regression analysis was performed to calculate adjusted odds ratios mutually controlling for both exposures and all patient characteristics and comorbidities assessed in the bivariate comparisons.

To determine with greater certainty whether a prior occupant or roommate was the source of exposure, we compared isolates for a sample of exposed case-roommate and case-prior-occupant pairs. Because molecular typing of isolates was not available, we compared antimicrobial susceptibilities based on available antibiogram data. *Klebsiella pneumoniae* was selected for this subanalysis due to the range of antibiotics tested for this organism in the study institutions. The tested antibiotics included cefepime, ceftriaxone, gentamicin, imipenem, levofloxacin, meropenem, piperacillin-tazobactam, tobramycin, and trimethoprim.

RESULTS

Patient admissions across the 4 facilities totaled 761,426 during the study period. Overall, 10,289 HAI cases were identified, and eligible controls were available for 10,033 cases (97.5%). The median length of stay for cases was 25 days (interquartile range, 14–46). Table 1 displays bivariate comparisons between cases and controls with respect to demographic characteristics, comorbid conditions, and exposure to infected or colonized roommates and prior bed occupants by organism. In total, 136 cases were exposed to a prior bed occupant with the same organism compared with 20 controls (crude odds ratio [OR], 6.88; 95% confidence interval [CI], 4.30– 11.01). Furthermore, 309 cases were exposed to a roommate with the same organism compared with 64 controls (crude OR, 4.95; 95% CI, 3.78–6.49). Less than 2% of cases were exposed to a previous bed occupant with the same organism and <4% of cases were exposed to roommates with the same organism (Figure 2). In the multivariable analysis controlling for patient characteristics and mutually controlling for each exposure, the odds of cases having been exposed to a prior bed occupant with the same organism were 5.83 times that of controls (95% CI, 3.62–9.39), and the odds of cases having been exposed to a roommate with the same organism were 4.82 times that of controls (95% CI, 3.67–6.34) (Table 2).

In the *K. pneumoniae* subanalysis comparing antibiotic sensitivity of case isolates with roommate isolates, antibiogram data were available for 38 of 43 exposed case-roommate pairs. Among them, 22 pairs (58%) had identical susceptibility profiles. Notably, among the remaining 16 pairs, most (n = 11, 69%) displayed additional antibiotic resistance in the case isolate, leaving open the possibility that resistance was acquired during the roommate's course of treatment and that the more resistant isolate was passed on to the case. For prior room-occupant pairs, susceptibility data were available for 20 of 27 pairs and 11 of those (55%) had identical susceptibility profiles. Among the remaining 9 pairs, 6 (67%) displayed additional antibiotic resistance in the case isolate.

DISCUSSION

The long campaign toward improving patient safety and reducing preventable deaths in hospitals has had many successes.[12,13] Still, too many Americans continue to die unnecessarily from infections they contract while in the hospital.[4] The need to focus on prevention is ever more acute with the proliferation of multidrug resistant organisms and increasingly limited options for successful treatment.[14]

We now have strong evidence that interventions designed to improve environmental cleanliness do make a difference. Indeed, the first multicenter randomized controlled trial to determine the efficacy of enhanced terminal cleaning

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TABLE 1. Bivariate Comparisons Between Cases and Controls With Respect to Demographic Characteristics, Comorbid Conditions, and Exposure to Infected or Colonized Roommates and Prior Bed Occupants[a]

	Sensitive Isolates			Resistant Isolates		
Variable	Cases	Controls	*P* Value	Cases	Controls	*P* Value
Acinetobacter baumannii	N = 258	N = 258		N = 214	N = 214	
Infected or colonized prior occupant	3 (1.1)	0 (0)	.25	6 (2.8)	0 (0)	.01
Infected or colonized roommate	3 (1.1)	0 (0)	.25	16 (7.5)	1 (0.5)	<.001
Age, y	54.6 (25.6)	54.2 (25.8)	.84	46.6 (30.3)	47.5 (30.8)	.74
Charlson comorbidity index	5.9 (5.2)	4.9 (4.8)	.02	3.7 (5.5)	3.7 (4.1)	.97
Female	113 (43.8)	126 (48.8)	.25	116 (54.2)	116 (54.2)	1.00
Malignancies	51 (19.8)	30 (11.6)	.01	20 (9.4)	27 (12.6)	.28
Renal failure	93 (36.1)	59 (22.9)	.001	24 (11.2)	18 (8.4)	.33
Diabetes mellitus	61 (23.6)	53 (20.5)	.40	36 (16.8)	37 (17.3)	.90
Enterococci	N = 1,259	N = 1,259		N = 1,238	N = 1,238	
Infected or colonized prior occupant	13 (1.0)	2 (0.2)	.004	28 (2.3)	2 (0.2)	<.001
Infected or colonized roommate	32 (2.5)	3 (0.2)	<.001	25 (2.0)	5 (0.4)	<.001
Age, y	54.5 (25.3)	52.9 (26.3)	.10	60.0 (19.1)	56.6 (24.1)	<.001
Charlson comorbidity index	5.7 (6.0)	4.9 (5.2)	<.001	6.7 (4.4)	5.3 (5.6)	<.001
Female	559 (44.4)	523 (41.5)	.15	579 (46.8)	570 (46.0)	.72
Malignancies	264 (20.1)	210 (16.7)	.006	417 (33.7)	191 (15.4)	<.001
Renal failure	343 (27.2)	258 (20.5)	<.001	457 (36.9)	310 (25.0)	<.001
Diabetes mellitus	313 (24.9)	259 (20.6)	.01	296 (23.9)	285 (23.0)	.60
Klebsiella pneumoniae	N = 1,091	N = 1,091		N = 629	N = 629	
Infected or colonized prior occupant	20 (1.8)	1 (0.1)	<.001	7 (1.1)	1 (0.2)	.07
Infected or colonized roommate	36 (3.3)	11 (1.0)	<.001	7 (1.1)	3 (0.5)	.34
Age, y	55.8 (25.4)	52.1 (27.1)	.001	57.4 (22.9)	55.1 (25.2)	.09
Charlson comorbidity index	6.4 (5.4)	4.4 (4.0)	.001	6.6 (5.0)	5.0 (5.2)	<.001
Female	508 (46.6)	501 (45.9)	.76	292 (46.4)	283 (45.0)	.61
Malignancies	340 (31.2)	143 (13.1)	<.001	151 (24.0)	88 (14.0)	<.001
Renal failure	324 (29.7)	214 (19.6)	<.001	228 (36.3)	136 (21.6)	<.001
Diabetes mellitus	234 (21.5)	216 (19.8)	.34	165 (26.2)	135 (21.5)	.047
Pseudomonas aeruginosa	N = 1,027	N = 1,027		N = 500	N = 500	
Infected or colonized prior occupant	11 (1.1)	0 (0)	<.001	1 (0.2)	0 (0)	.999
Infected or colonized roommate	51 (5.0)	6 (0.6)	<.001	11 (2.2)	1 (0.2)	.006
Age, y	57.6 (25.1)	53.7 (25.4)	<.001	58.9 (22.8)	57.4 (23.2)	.33
Charlson comorbidity index	6.1 (4.7)	4.8 (4.7)	<.001	5.6 (4.1)	5.2 (4.5)	.10
Female	474 (46.2)	462 (54.0)	.60	236 (47.2)	232 (46.4)	.80
Malignancies	219 (21.3)	144 (14.0)	<.001	76 (15.2)	62 (12.4)	.20
Renal failure	277 (27.0)	221 (21.5)	.004	157 (31.4)	109 (21.8)	<.001
Diabetes mellitus	244 (23.8)	200 (19.5)	.02	138 (27.6)	123 (24.6)	.28
Staphylococcus aureus	N = 2,008	N = 2,008		N = 1,632	N = 1,632	
Infected or colonized prior occupant	21 (1.1)	9 (0.5)	.03	26 (1.6)	5 (3.5)	<.001
Infected or colonized roommate	81 (4.0)	25 (1.3)	<.001	46 (2.8)	9 (0.6)	<.001
Age, y	50.8 (25.8)	52.0 (26.6)	.15	60.5 (22.4)	56.1 (24.3)	<.001
Charlson comorbidity index	5.3 (4.9)	4.5 (4.4)	<.001	6.6 (4.5)	4.9 (4.5)	<.001
Female	824 (41.0)	873 (43.5)	.12	678 (41.5)	731 (44.8)	.06
Malignancies	335 (16.7)	223 (11.1)	<.001	309 (18.9)	207 (12.7)	<.001
Renal failure	475 (23.7)	394 (19.6)	.002	564 (34.6)	351 (21.5)	<.001
Diabetes mellitus	443 (22.1)	445 (22.2)	.94	459 (28.1)	361 (22.1)	<.001
Streptococcus pneumoniae	N = 107	N = 107		N = 70	N = 70	
Infected or colonized prior occupant	0 (0)	0 (0)	N/A	0 (0)	0 (0)	N/A
Infected or colonized roommate	0 (0)	0 (0)	N/A	1 (1.4)	0 (0)	.999
Age, y	55.6 (23.4)	56.7 (26.6)	.75	49.9 (23.2)	50.2 (28.4)	.94
Charlson comorbidity index	4.8 (4.1)	5.6 (4.5)	.27	5.8 (5.6)	3.9 (3.6)	.02
Female	44 (41.1)	44 (44.1)	1.00	20 (28.6)	29 (41.4)	.11
Malignancies	17 (15.9)	13 (12.2)	.43	13 (18.6)	0 (0)	<.001
Renal failure	26 (24.3)	26 (24.3)	1.00	14 (20.0)	12 (17.1)	.66
Diabetes mellitus	19 (17.8)	18 (16.8)	.86	15 (21.4)	12 (17.1)	.52

[a]Categorical variables are number (%), with bivariate comparisons conducted using the χ^2 test for independence or the Fisher exact test. Continuous variables are mean (standard deviation) with bivariate comparisons conducted using a 2-sample *t* test.

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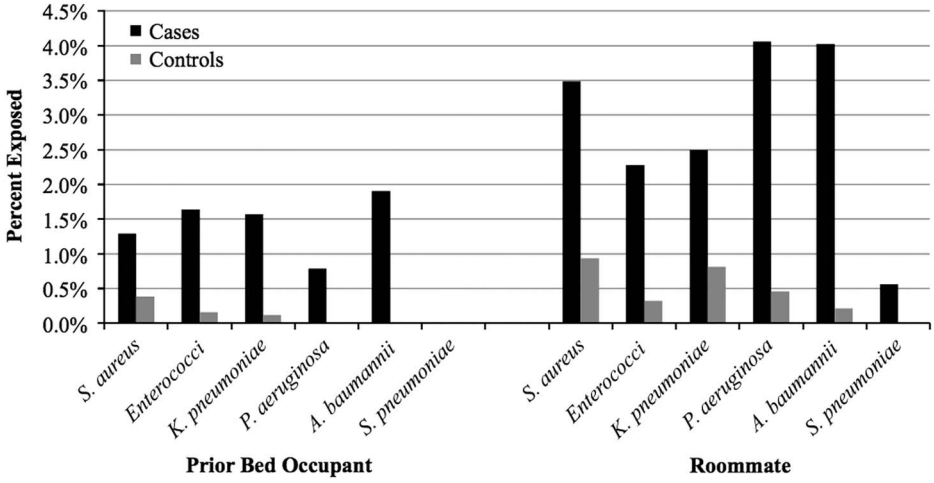

FIGURE 2. Percent of patients exposed to infected prior bed occupants and roommates in controls versus cases having healthcare-associated infections with *Staphylococcus aureus*, *Acinetobacter baumannii*, *Streptococcus pneumoniae*, *Pseudomonas aeruginosa, Klebsiella pneumoniae, Enterococcus faecalis*, and *Enterococcus faecium* exposed to prior bed occupants and roommates infected or colonized with the same organism.

TABLE 2. Association Between Healthcare-Associated Infection and Exposure to Infected or Colonized Prior Bed Occupants and Roommates

Exposure	Odds Ratio (95% CI)[a]
Exposure to infected or colonized prior occupant	5.83 (3.62–9.39)
Exposure to infected or colonized roommate	4.82 (3.67–6.34)
Age, y	1.00 (0.999–1.001)
Charlson comorbidity index	1.04 (1.03–1.05)
Female	1.00 (0.95–1.06)
Malignancies	1.61 (1.48–1.76)
Renal failure	1.50 (1.40–1.60)
Diabetes mellitus	1.03 (0.96–1.11)

NOTE. CI, confidence interval.
[a]Results of multivariable logistic regression analysis.

procedures for patients with multidrug-resistant organisms was recently published. This study of 9 hospitals showed a statistically significant decrease in organism acquisition when targeted cleaning methods—particularly ultraviolet light technology—were incorporated into the standard cleaning protocol, adding only 4 extra minutes to the total cleaning time.[15] Although some roommate-to-roommate transmission may occur outside of the physical environment (eg, with healthcare workers serving as vectors), it is likely that at least some roommate transmission and all prior occupant transmission involves environmental reservoirs.

As the largest study to quantify the association between HAIs and exposure to infected or colonized previous bed occupants and roommates, encompassing data from all inpatient units in 4 acute-care hospitals and surveying exposure to 6 different organisms, our analysis serves to illustrate how many infections might be prevented by implementing enhanced cleaning measures. Previous studies showed mixed findings due to wide variations in sample size, study quality, design, patient population, and definitions of exposures and outcomes, though the majority did find statistically significant relationships between at least 1 of their exposures and outcomes of interest.[16] Our findings reveal robust and statistically significant associations, with exposure to an infected or colonized prior bed occupant conferring a nearly 6-fold increase in the odds of infection, and exposure to an infected or colonized roommate conferring a nearly 5-fold increase. These results might actually underestimate the true association because, by limiting the retrospective period to the most likely period of exposure (3–5 days prior to infection), we captured only a portion of roommates and prior room occupants who could have been sources of exposure.[11] Still, the prevalence of exposure as operationalized in this analysis was low, suggesting that the overall contribution of prior bed occupants and roommates defined in this way to the overall incidence of HAIs is relatively small.

The primary limitation of this study was the unavailability of molecular typing, which made it impossible to determine with certainty whether a case acquired a pathogen genetically identical to that of the roommate or prior occupant presumed to be the source of exposure. Nonetheless, our conclusion that there is a true chain of transmission from prior bed occupants and roommates remains plausible for 2 reasons. First, we performed a subanalysis to assess whether isolates were phenotypically similar regarding their susceptibility to a variety of antibiotic agents and still found statistically significant associations between prior bed occupant or roommate exposure and the development of HAIs. Furthermore, in most cases where antibiotic sensitivity did differ, resistance was more prevalent among the cases than among the prior occupants or

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roommates presumed sources of exposure. This finding supports the possibility that resistance could have been acquired during the roommate or prior occupant's antibiotic therapy, with the resistant organism then passed to the case.[17] Second, the epidemiological association we identified remained sizeable and highly significant even after controlling for several potential confounders. However, the association could be due to an unknown confounder that we were unable to identify or measure in this retrospective study. For example, certain rooms may be reserved for the highest-risk patients, meaning that patients assigned to such rooms could have a both a higher risk of exposure due to their room placement as well as a higher risk of infection due to their condition upon admission to the unit. Indeed, some statistically significant differences between cases and controls were observed at baseline regarding the comorbid conditions that affect infection risk. However, the associations remained robust in the multivariable model controlling for these variables, suggesting that confounding by factors related to patient severity was minimal if at all present. Finally, with the exception of unit-specific protocols in response to outbreaks, universal surveillance was not conducted at the study institutions, meaning that some colonization may have gone undetected.

The human and financial costs associated with HAIs are unacceptably high and may continue to grow along with antimicrobial resistance and the shortage of novel therapies on the immediate horizon.[14] In light of mounting evidence that patients harboring pathogens do contaminate their hospital rooms,[18] that current standards for cleaning and disinfection are not sufficient for decontamination,[19] and that exposure to contaminated rooms confers a 5- to 6-fold increase in odds of infection, hospitals must take action by adopting proven methods for reducing environmental contamination.

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REFERENCES

1. Klevens RM, Edwards JR, Richards CL, et al. Estimating health care-associated infections and deaths in US hospitals, 2002. *Public Health Rep* 2007;122:160–166.
2. Scott RD II. The direct medical costs of healthcare-associated infections in US hospitals and the benefits of prevention. Centers for Disease Control and Prevention website. http://www.cdc.gov/hai/pdfs/hai/scott_costpaper.pdf. Published 2009. Accessed July 27, 2017.
3. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med* 2014;370:1198–1208.
4. Umscheid CA, Mitchell MD, Doshi JA, Agarwal R, Williams K, Brennan PJ. Estimating the proportion of healthcare-associated infections that are reasonably preventable and the related mortality and costs. *Infect Control Hosp Epidemiol* 2011;32:101–114.
5. Jeeva RR, Wright D. Healthcare-associated infections: a national patient safety problem and the coordinated response. *Med Care* 2014;52:S4–S8.
6. Stone PW, Glied SA, McNair PD, et al. CMS changes in reimbursement for HAIs: setting a research agenda. *Med Care* 2010;48:433–439.
7. Ranji SR, Shetty K, Posley KA, et al. Closing the quality gap: a critical analysis of quality improvement strategies (vol. 6, Prevention of healthcare–associated infections). Technical Review, No. 9.6. Rockville, MD: Agency for Healthcare Research and Quality (US); 2007.
8. Dancer SJ. The role of environmental cleaning in the control of hospital-acquired infection. *J Hosp Infect* 2009;73:378–385.
9. Boyce JM. Modern technologies for improving cleaning and disinfection of environmental surfaces in hospitals. *Antimicrob Resist Infect Control* 2016;5:10.
10. Apte M, Neidell M, Furuya EY, Caplan D, Glied S, Larson E. Using electronically available inpatient hospital data for research. *Clin Transl Sci* 2011;4:338–345.
11. Horan TC, Andrus M, Dudeck MA. CDC/NHSN surveillance definition of health care-associated infection and criteria for specific types of infections in the acute care setting. *Am J Infect Control* 2008;36:309–332.
12. Institute of Medicine. Crossing the quality chasm: a new health system for the 21st century. National Academy Press website. http://www.nationalacademies.org/hmd/~/media/Files/Report%20Files/2001/Crossing-the-Quality-Chasm/Quality%20Chasm%202001%20%20report%20brief.pdf. Published 2001. Accessed January 24, 2018.
13. Wang Y, Eldridge N, Metersky ML, et al. National trends in patient safety for four common conditions, 2005–2011. *N Engl J Med* 2014;370:341–351.
14. Bassetti M, Merelli M, Temperoni C, Astilean A. New antibiotics for bad bugs: where are we? *Ann Clin Microbiol Antimicrob* 2013;12:22.
15. Anderson DJ, Chen LF, Weber DJ, et al. Enhanced terminal room disinfection and acquisition and infection caused by multidrug-resistant organisms and *Clostridium difficile* (the Benefits of Enhanced Terminal Room Disinfection study): a cluster-randomised, multicentre, crossover study. *Lancet* 2017;389:805–814.
16. Cohen B, Cohen CC, Loyland B, Larson EL. Transmission of health care-associated infections from roommates and prior room occupants: a systematic review. *Clin Epidemiol* 2017;9:297–310.
17. Freedberg DE, Salmaian H, Cohen B, Abrams JA, Larson EL. Receipt of antibiotics in hospitalized patients and risk for *Clostridium difficile* infection in subsequent patients who occupy the same bed. *JAMA Intern Med* 2016;176:1801–1808.
18. Russotto V, Cortegiani A, Raineri SM, Giarratano A. Bacterial contamination of inanimate surfaces and equipment in the intensive care unit. *J Intensive Care* 2015;3:54.
19. Siani H, Maillard JY. Best practice in healthcare environmental decontamination. *Eur J Clin Microbiol Infect Dis* 2015;34:1–11.