Transmission of health care-associated infections from roommates and prior room occupants: a systematic review

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Abstract: Pathogens that cause health care-associated infections (HAIs) are known to survive on surfaces and equipment in health care environments despite routine cleaning. As a result, the infection status of prior room occupants and roommates may play a role in HAI transmission. We performed a systematic review of the literature evaluating the association between patients’ exposure to infected/colonized hospital roommates or prior room occupants and their risk of infection/colonization with the same organism. A PubMed search for English articles published in 1990–2014 yielded 330 studies, which were screened by three reviewers. Eighteen articles met our inclusion criteria. Multiple studies reported positive associations between infection and exposure to roommates with influenza and group A streptococcus, but no associations were found for Clostridium difficile, methicillin-resistant Staphylococcus aureus, Cryptosporidium parvum, or Pseudomonas cepacia; findings were mixed for vancomycin-resistant enterococci (VRE). Positive associations were found between infection/colonization and exposure to rooms previously occupied by patients with Pseudomonas aeruginosa and Acinetobacter baumannii, but no associations were found for resistant Gram-negative organisms; findings were mixed for C. difficile, methicillin-resistant S. aureus, and VRE. Although the majority of studies suggest a link between exposure to infected/colonized roommates and prior room occupants, methodological improvements such as increasing the statistical power and conducting universal screening for colonization would provide more definitive evidence needed to establish causality.

Keywords: health care-associated infections, hospital roommates, prior room occupants, multidrug-resistant organisms

Introduction

Despite decades of infection prevention research and quality improvement initiatives, health care-associated infections (HAIs) remain common adverse events in hospitals and long-term care facilities.¹ Over 700,000 HAIs occur annually in the USA alone, leading to death in 6% of cases and costing the health care system 28–45 billion US dollars each year.²–⁴ Recently, there has been renewed interest in understanding the role of the physical environment in the spread of HAIs.⁵,⁶ Countless studies have reported that pathogenic organisms can survive on a variety of fomites in health care settings, including those at the patient bedside (eg, mattresses, linens, pillows, bedframes, bedrails), inside patient bathrooms (eg, toilets, floors, soap dispensers), and on medical instruments (eg, blood pressure cuffs, suctioning systems).⁷–¹⁴ Moreover, the effectiveness of cleaning regimens has been called into question as a number of studies have reported that pathogens remain on hospital surfaces even after they have been disinfected in accordance with recommended protocols.¹⁵–¹⁸ Pathogens that survive on
fomites can subsequently be transferred from contaminated surfaces to patients through direct contact, indirect contact through the hands and gloves of health care workers, or by aerosolization of surface particles.8,11,19–21

Patients hospitalized with infections frequently contaminate their surrounding environments with pathogenic organisms; therefore, roommates and previous room occupants may serve as potential sources of exposure to other patients.8,22 Yet, our understanding of how such exposures contribute to a patient’s overall risk of infection remains limited, and the effects of these exposures may be dependent on a variety of factors unique to each organism species, such as their robustness to atmospheric conditions, susceptibility to cleaning agents, and virulence. Therefore, the aim of this study was to systematically review the literature describing organism transmission from concurrent roommates or previous room occupants in health care settings.

Methods

Inclusion criteria

This systematic literature review was performed in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis guidelines.23 Studies were included if they met the following criteria: 1) compared infection and/or colonization rates between patients known to be exposed to infectious roommates and/or prior room occupants and patients not known to be exposed, 2) were conducted in an acute or long-term health care setting, 3) were original research studies, 4) were published in English, and 5) were published from January 1, 1990 through December 31, 2014.

Search strategy

The literature search was conducted in February 2015 to ensure that all manuscripts published within the inclusion period had been indexed. All databases indexed within PubMed were searched using the following combination of keywords and Medical Subject Heading (MeSH) search terms linked with Boolean operators: ([MeSH {Patients’ Rooms}] AND [MeSH {Infection Control Practitioners}] OR MeSH {Infection Control} OR MeSH {Cross Infection} OR MeSH {Infection} OR MeSH {Wound Infection} OR MeSH {Surgical Wound Infection} OR Keyword {Infection}) OR (Keyword [Prior Room Occupant(*)] OR (Keyword [Roommate] AND Keyword [Transmission] OR Keyword [Infection(*)] OR Keyword [Outbreak*] ).

Article selection, review, and quality scoring

Three reviewers (BC, CCC, and BL) independently assessed each article at all stages of the review and quality scoring processes. Discrepancies among reviewers were discussed as a group until a consensus was reached. First, the reviewers screened the titles and abstracts of all articles and eliminated those that were not relevant to the aims of the review. The remaining articles underwent full-text review to determine whether they met the inclusion criteria. A hand search of the references of all articles meeting the inclusion criteria was also performed. Articles meeting the inclusion criteria were scored according to a modified 20-item version of the Checklist for Measuring Study Quality developed by Downs and Black (Table 1).24 Some measures were not applicable to all articles; these items were removed from the score denominator and not assessed for studies in which they were not relevant. Final scores were converted to percentages.

Results

The database search returned 330 articles. No additional articles were identified from the hand search and no duplicates were found. Twenty articles were excluded during the title screening phase, and 223 articles were excluded during the abstract screening phase. The remaining 87 articles underwent full-text review, and 18 of these were determined to meet the inclusion criteria. Figure 1 describes the reasons for exclusion during the full-text review. Ten articles investigated the effects of exposure to infected or colonized roommates,25–34 six investigated the effects of exposure to infected or colonized prior room occupants,35–40 and two investigated both exposures.41,42

Study designs and definitions of exposures and outcomes

The articles in this review represent a range of observational and interventional designs, including retrospective and prospective cohort studies (n=11),26,28–32,35,38–40,42 case–control studies (n=4),25,27,33,34 and quasi-experimental studies (n=3).36,37,41 The studies varied considerably in their definitions of exposure and outcome measures. Among studies that examined exposure to roommates with nonviral pathogens, four (44%) defined the exposure as having a roommate with a clinical infection25–27,42 and five (56%) defined the exposure as having a roommate who was either infected or colonized.31–34,41 Among studies that examined exposure to
## Table 1 Assessment of study quality

| Quality measure                                                                 | Yes (%) | No (%) | Cannot determine | Not applicable |
|--------------------------------------------------------------------------------|---------|--------|------------------|----------------|
| 1. Is the hypothesis/aim/objective of the study clearly described?             | 18 (100)| 0      | 0                | 0              |
| Population, intervention or exposure, and outcome included? Yes=1; No=0        |         |        |                  |                |
| Note: Score may be based on study’s main aim                                   |         |        |                  |                |
| 2. Are the main outcomes to be measured clearly described in the introduction or methods section? Yes=1; No=0 | 17 (94) | 1 (6)  | 0                | 0              |
| Enough information provided to replicate study                                |         |        |                  |                |
| 3. Are the characteristics of the patients included in the study clearly described? Yes=1; No=0 | 18 (100)| 0      | 0                | 0              |
| General patient population and inclusion/exclusion criteria described?         |         |        |                  |                |
| Note: Descriptive statistics not required                                       |         |        |                  |                |
| 4. Is exposure of interest clearly described?                                   | 15 (83) | 3 (17) | 0                | 0              |
| Enough information provided to replicate study                                 |         |        |                  |                |
| Note: Score based on exposure of interest (ie, prior room occupant and/or roommate infection status) |         |        |                  |                |
| 5. Are the distributions of principal confounders in each group of subjects to be compared clearly described? | 13 (72) | 0      | 0                | 0              |
| Most clinically relevant characteristics described:2; only a few general patient characteristics described:1; no characteristics described:0 |         |        |                  |                |
| 6. Are the main findings of the study clearly described?                        | 18 (100)| 0      | 0                | 0              |
| Results presented for all proposed analyses and outcome measures? Yes=1; No=0 |         |        |                  |                |
| 7. Does the study provide estimates of the random variability in the data for the main outcomes? Yes=1; No=0 | 18 (100)| 0      | 0                | 0              |
| Confidence intervals, p-values, or other measures of standard error included? |         |        |                  |                |
| Note: Score based on analyses for roommate and/or prior room occupant exposures |         |        |                  |                |
| 8. Have the characteristics of patients lost to follow-up been described?      | 2 (11)  | 0      | 0                | 16 (89%)       |
| If loss to follow-up is implied, are patients described or compared to those who participated? Yes=1; No=0 |         |        |                  |                |
| Note: If loss to follow-up not mentioned by authors, item scored as “not applicable” and removed from denominator |         |        |                  |                |
| 9. Have actual probability values been reported for the main outcomes except where p<0.001? Yes=1; No=0 | 18 (100)| 0      | 0                | 0              |
| Note: Score based on analyses for roommate and/or prior room occupant exposures |         |        |                  |                |
| 10. Were patients selected in a way that is representative of the source population the authors identified in the inclusion/exclusion criteria? | 16 (89)| 0      | 2 (11%)          | 0              |
| All patients identified in the source population included:1; certain patients included in the source population systematically excluded (eg, patients who died, were transferred, refused participation, etc):0 |         |        |                  |                |
| Note: Zero was scored if authors did not provide enough information to determine representativeness |         |        |                  |                |
| 11. Were the staff, places, and facilities where the patients were treated representative of the treatment the majority of patients receive? Facility similar to other institutions of the same type? Yes=1; No=0 | 17 (94)| 0      | 1 (6%)           | 0              |
| Note: Zero was scored if authors did not provide enough information to determine representativeness |         |        |                  |                |
| 12. If any of the results of the study were based on “data dredging”, was this made clear? All subgroup analyses described in methods section or noted as post hoc analyses=1; unplanned subgroup analyses presented and not noted as post hoc=0 | 0      | 0      | 2 (11%)          | 16 (89%)       |
| Note: If study included no subgroup analyses, item scored as “not applicable” and removed from denominator |         |        |                  |                |
Table 1 (Continued)

| Quality measure                                                                 | Yes (%) | No (%) | Cannot determine | Not applicable |
|---------------------------------------------------------------------------------|---------|--------|------------------|----------------|
| 13. Do the analyses adjust for different lengths of follow-up of patients,      | 8 (44)  | 6 (33) | 0                 | 4 (22%)        |
| or in case–control studies, is the time period between the intervention          |         |        |                   |                |
| and outcome the same for cases and controls? If follow-up is differential         |         |        |                   |                |
| between groups, was this controlled for in the design or analysis? Yes=1; No=0   |         |        |                   |                |
| Note: If follow-up is same for all patients, item scored as “not applicable” and |         |        |                   |                |
| removed from denominator                                                        |         |        |                   |                |
| 14. Were the statistical tests used to assess the main outcomes appropriate?    | 15 (83) | 3 (17) | 0                 | 0              |
| Statistical tests minimally appropriate for the data and research questions?    |         |        |                   |                |
| Yes=1; No=0                                                                     |         |        |                   |                |
| 15. Were the main outcome measures used valid and reliable?                      | 16 (89)| 1 (6)  | 0                 | 1 (6%)         |
| Systematic, repeatable methods of case finding and appropriate lab definitions |         |        |                   |                |
| used? Yes=1; No=0                                                                |         |        |                   |                |
| Note: Zero was scored if authors did not provide enough information to assess    |         |        |                   |                |
| outcome measures                                                                  |         |        |                   |                |
| 16. Were the patients in different intervention groups or cases and controls     | 18 (100)| 0      | 0                 | 0              |
| recruited from the same population? Yes=1; No=0                                  |         |        |                   |                |
| 17. Were the study subjects in different intervention groups or cases and        | 18 (100)| 0      | 0                 | 0              |
| controls recruited over the same period of time? Yes=1; No=0                    |         |        |                   |                |
| 18. Was there adequate adjustment for confounding in the analyses from which the | 9 (50)  | 6 (33) | 3 (17%)           | 0              |
| main findings were drawn? Key confounders included in multivariable models? Yes= |         |        |                   |                |
| 1; No=0                                                                         |         |        |                   |                |
| Note: Score based on exposure of interest (ie, prior room occupant and/or      |         |        |                   |                |
| roommate infection status                                                       |         |        |                   |                |
| 19. Were losses of patients to follow-up taken into account? If loss to         | 1 (6)   | 1 (6)  | 16 (89%)          | 0              |
| follow-up is reported, is an appropriate statistical method used to account     |         |        |                   |                |
| for this? Yes=1; No=0                                                            |         |        |                   |                |
| Note: If no loss to follow-up is reported, item scored as “not applicable” and |         |        |                   |                |
| removed from denominator. Zero was scored if authors did not provide enough    |         |        |                   |                |
| information to assess loss to follow-up                                          |         |        |                   |                |
| 20. Did the study have sufficient power to detect a clinically important        | 0       | 4 (22)| 14 (78%)          | 0              |
| effect where the probability value for a difference being due to chance is <5%? |         |        |                   |                |
| Power calculation included and adequate power reported=1; power calculation     |         |        |                   |                |
| included and inadequate power reported or no power calculation mentioned=0       |         |        |                   |                |
| Note: Score based on exposure of interest (ie, prior room occupant and/or       |         |        |                   |                |
| roommate infection status). Zero was scored if authors did not provide enough   |         |        |                   |                |
| information to assess power                                                     |         |        |                   |                |

Note: *Data collection tool from Downs and Black.24*  

previous room occupants, there was variation both in the determination of whether a previous occupant was infectious and in the timeframe during which they occupied the room. Four studies (50%) defined the exposure as a previous occupant who was infected or colonized,35,38,39,41 two studies (25%) – both of *Clostridium difficile* – defined the exposure as a previous occupant with a history of infection,40,41 and two studies (25%) did not specify.36,37

With regard to timing of the exposure, most of the studies implied that only the occupant immediately prior to the study subject was included, although only three articles stated this explicitly.35,37,40 One study also analyzed exposure to any infectious patient who had occupied the same room within the previous 2-week period.37 Finally, there was notable variation in the definition of study outcomes. Half of the articles used an outcome measure of infection,25–30,32,40,42 while the other half used an outcome measure of infection or colonization.31,33–39,41 Methods of case detection ranged from universal screening to sampling based on clinical indication.
Findings of studies examining exposure to infected or colonized roommates

The 12 articles investigating the effects of exposure to infected or colonized roommates are described in Table 2 and their findings are summarized in Figure 2. Five studies evaluated bacterial pathogens that are transmitted by contact.31,33,34,41,42 No significant associations between roommate exposure and infection with methicillin-resistant Staphylococcus aureus (MRSA), C. difficile, or Pseudomonas cepacia were identified.31,33,42 Results for vancomycin-resistant enterococci (VRE) were inconsistent, with Bass et al41 reporting a statistically significant positive association (hazard ratio [HR]: 18.8, 95% confidence interval: [5.4–66.2]) and Shorman and Al-Tawfiq34 reporting a statistically significant negative association (odds ratio [OR]: 0.04 [0.004–0.4]).

Three studies conducted in long-term care settings examined group A streptococcus, which is transmitted by contact and droplet routes.25,27,32 All three found significant positive associations between roommate exposure and infection, with ORs ranging from 2.0 (1.1–5.1) to 15.3 (2.5–110.9; point estimate not reported by Auerbach et al25).

Three studies examined exposure to patients with Acinetobacter baumannii and Pseudomonas aeruginosa, which are transmitted by contact and airborne transmission. Nseir et al39 found that exposure to rooms previously occupied by patients with Acinetobacter baumannii and Pseudomonas aeruginosa resulted in significantly higher odds of infection or colonization (OR: 4.2 [2.0–8.8] and OR: 2.3 [1.2–4.3], respectively), while the two studies that examined extended-spectrum beta-lactamase-producing gram-negative organisms found no association.35,39 Effects of exposure to rooms previously occupied by patients with C. difficile, MRSA, and VRE were examined by at least two studies each. For each of these organisms, significant

Findings of studies examining exposure to rooms previously occupied by infected or colonized patients

The eight articles investigating the effects of exposure to rooms previously occupied by infected or colonized patients are described in Table 3 and their findings are summarized in Figure 3. All of the articles studied bacterial pathogens spread through contact transmission in acute care hospitals, with all but two41,42 taking place in intensive care units. Nseir et al39 found that exposure to rooms previously occupied by patients with Acinetobacter baumannii and Pseudomonas aeruginosa resulted in significantly higher odds of infection or colonization (OR: 4.2 [2.0–8.8] and OR: 2.3 [1.2–4.3], respectively), while the two studies that examined extended-spectrum beta-lactamase-producing gram-negative organisms found no association.35,39 Effects of exposure to rooms previously occupied by patients with C. difficile, MRSA, and VRE were examined by at least two studies each. For each of these organisms, significant
Table 2 Summary and quality assessment of studies reporting associations between health care-associated infection and exposure to infected or colonized roommates

| Author, quality score | Study period | Setting | Design | Subjects |
|-----------------------|--------------|---------|--------|----------|
| Auerbach et al³⁵      | August 1989–February 1990 | 50-bed nursing home, North Carolina | Outbreak investigation and case–control | All residents who underwent diagnostic testing for GAS, excluding those who died from causes other than GAS |
| Bass et al²⁷         | March 2010–October 2010 | 34-bed hematology–oncology ward in 427-bed tertiary care teaching hospital, Melbourne, Australia | Quasi-experimental | All pts w/neg VRE rectal swab upon admission and no known history of VRE |
| Bruce et al²⁶       | August 1994–October 1996 | Special Immunity Service ward for HIV-pos pts, Grady Memorial Hospital | Retrospective cohort | Exposed: all roommates of pts w/Cryptosporidium stool sample and no prior history; unexposed: roommates of pts w/o Cryptosporidium matched by nearest CD4 count and hospitalization date |
| Chang and Nelson⁴²  | March 1987–August 1987 | 305-bed community hospital, Baltimore, MD | Retrospective cohort | All pts w/LOS >48 h |
| Deutscher et al³⁴    | October 2007–February 2008 | 57-bed long-term acute care hospital, New Mexico | Case–control | Cases: all pts w/incident GAS infection >48 h after admission; controls: randomly selected pts w/o GAS symptoms or cultures |
| Drinka et al²⁸      | 1993–2000 | Wisconsin Veterans Home, a 635-bed skilled nursing facility | Retrospective cohort | All residents |
| Drinka et al²⁹      | 1992–1993 influenza season | Wisconsin Veterans Home, a 635-bed skilled nursing facility | Retrospective cohort | All residents |
| Forns et al³⁰       | August 2000–October 2002 | Three-ward liver unit in tertiary care center | Prospective cohort | All pts w/neg anti-HCV screen upon ward admission |
| Furuno et al³¹      | March 2005–September 2008 | 120-bed Baltimore Rehabilitation and Extended Care Center, 150-bed Perry Point VA Medical Center, 180-bed University Specialty Hospital, Maryland | Prospective cohort | All residents w/o history of MRSA colonization, ≥1 neg MRSA screen from anterior nares or skin breakdown at enrollment, LOS >7 days, and ≥1 follow-up culture |
| Greene et al³²      | January 2001–December 2001 | 120-bed long-term care facility, Georgia | Retrospective cohort | All residents |
| Pegues et al³³      | August 1989–September 1989 | St Christopher’s Hospital for Children, a 350-bed pediatric referral center, Philadelphia, PA | Case–control | Cases: CF pts w/initial isolation of Pseudomonas cepacia from respiratory secretions; controls: randomly selected CF pts w/neg P. cepacia sputum cultures |
| Shorman and Al-Tawfiq¹⁴ | February 2006–March 2010 | Tertiary care referral hospital, Damman, Saudi Arabia | Case–control | Cases: pts w/pos surveillance or clinical VRE cultures; controls: randomly selected pts w/neg clinical or surveillance VRE cultures |

Abbreviations: BMI, body mass index; CF, cystic fibrosis; CHF, congestive heart failure; GAS, group A streptococcus; HCV, hepatitis C virus; HIV, human immunodeficiency virus; HR, hazard ratio; LOS, length of stay; MRSA, methicillin-resistant Staphylococcus aureus; neg, negative; OR, odds ratio; pos, positive; P. cepacia, Pseudomonas cepacia; pts, patients; PVD, peripheral vascular disease; RR, relative risk; VRE, vancomycin-resistant enterococci; w/ with; w/o, without.
| N                      | Outcome                                                                 | Exposure                                                                 | Analysis                                                                 | Results                                                                 |
|------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|--------------------------------------------------------------------------|
| 37 roommate pairs      | Symptomatic or asymptomatic GAS infection detected by culture or serology | Roommate w/symptomatic or asymptomatic GAS infection                      | Two-tailed Fisher’s exact test                                           | 26 pairs concordant uninfected, 6 concordant infected, 5 pairs discordant p=0.0009 |
| 439 pts                | Incident VRE colonization detected by rectal surveillance culture         | Roommate w/VRE infection or colonization                                  | Cox proportional hazard adjusted for prior bed occupant status and study intervention phase | HR: 18.8 (5.4–66.2)                                                     |
| 74 pts (37 exposed, 37 unexposed) | Incident cryptosporidiosis                                               | Roommate w/cryptosporidiosis                                              | Unadjusted RR                                                            | RR undefined (one case in unexposed roommates, zero cases in exposed roommates) |
| 2,859 pts              | Incident *Clostridium difficile* diarrhea >48 h after admission and within 15 days of discharge | Roommate w/C. difficile diarrhea                                         | Unadjusted RR                                                            | RR: 2.7 (0.6–7.0)                                                       |
| 50 residents (11 cases, 39 controls) | Incident GAS infection >48 h after admission                             | Roommate w/GAS infection or colonization                                   | Logistic regression adjusted for age, sex, BMI, death, admission to special care unit, LOS >4 weeks, admission from home, *C. difficile*, diabetes, CHF, hypertension, PVD, chronic renal failure/dialysis, malignancy, ventilator, cellulitis, nonsurgical wound, neg pressure | OR: 15.3 (2.5–110.9)                                                   |
| 3,294 residents        | Culture confirmed influenza A infection                                  | Roommate w/pos influenza A culture                                        | Unadjusted RR comparing exposed to pos roommate versus single room       | RR: 3.1 (1.6–5.8)                                                     |
| 489 residents seasons  | Culture confirmed influenza B infection                                  | Roommate w/pos influenza B culture                                        | Unadjusted RR comparing exposed to pos roommate versus single room       | RR: 2.6 (1.2–5.6)                                                     |
| 1,301 pts              | Incident HCV infection assessed 6 months postdischarge                    | Roommate w/HCV infection                                                  | Unadjusted OR                                                            | OR: 12.0 (1.4–103.0)                                                   |
| Residential care: 286; rehabilitation care: 157 residents | Incident MRSA colonization in anterior nares or site of skin breakdown    | Roommate w/MRSA colonization                                               | Residential care: Cox proportional hazard adjusted for antibiotic therapy and bedbound status; rehabilitation care: Cox proportional hazard HR adjusted for bedbound status and limited mobility status | Residential care HR: 1.4 (0.5–3.9); rehabilitation care HR: 0.5 (0.1–2.2) |
| 125 residents          | GAS infection or colonization                                             | Roommate w/GAS colonization or infection                                  | Unadjusted and Mantel–Haenszel RR (variables included in multivariable not described) | Adjusted RR: 2.0 (1.1–4.0)                                           |
| 28 pts (14 cases, 14 controls) | Pos *P. cepacea* culture in pts hospitalized ≥1 time between last neg and first pos culture | Roommate w/pos *P. cepacea* culture                                       | Unadjusted OR                                                            | OR: 12.5 (0.6–607.0)                                                   |
| 90 pts (30 cases, 60 controls) | VRE colonization or infection                                             | Roommate with VRE infection or colonization                               | Unadjusted OR                                                            | OR: 0.04 (0.004–0.4)                                                   |
Positive associations were reported by one article (C. difficile, HR: 2.4 [1.2–4.5];34 MRSA, OR: 1.4 [p=0.04];36 VRE, HR: 3.8 [2.0–7.4]), with the remainder of articles finding no significant associations.38,41,42

Quality of included articles

Quality scores ranged from 50% to 95%, with the majority of articles scoring at or above 80% (median=83%, mean=82%). Table 1 provides a summary of scores for each item. All of the articles had clearly stated aims, adequate descriptions of study populations, appropriate control groups, and acceptable reporting of results. However, many of the studies did not appropriately control for confounding (50%, n=9), address differential follow-up between exposed and unexposed patients (33%, n=6), or use acceptable statistical methods (17%, n=3). In addition, some articles did not include sufficient or precise definitions of the exposures (17%, n=3) or outcomes (6%, n=1) under investigation. Notably, none of the articles reported a sample size calculation indicating adequate power to detect differences between patients exposed versus unexposed to infected/colonized roommates or prior room occupants.

Discussion

More than half of the articles identified in this systematic literature review reported at least one statistically significant

| Positive | Negative |
|----------|----------|
| C. difficile | Chang and Nelson42 Acute care, endemic, 94% |
| Cryptosporidium | Bruce et al43 Acute care, endemic, 50% |
| Group A Streptococcus | |
| Hepatitis C | |
| Influenza A | |
| Influenza B | |
| Methicillin-resistant Staphylococcus aureus | |
| Pseudomonas cepacia | |
| Vancomycin-resistant enterococci | Shorman and Al-Tawfiq34 Acute care, endemic, 76% |

Figure 2 Findings of studies investigating the association between health care-associated infection or colonization and exposure to infected or colonized roommates.

Notes: Studies reporting significant positive associations are represented in black circles and those reporting significant negative associations are represented in white circles. Studies that did not find statistically significant associations are represented in gray circles. Circles display study authors, setting, investigation of endemic versus epidemic pathogen, and quality score.
positive association between the infection/colonization status of a roommate or previous room occupant and the development of HAIs. Only a single article identified a statistically significant negative association. The remainder found no associations that reached statistical significance, though this may be due to the fact that they were insufficiently powered; none of the articles reviewed included a statement indicating that statistical power was adequate for the analyses presented. Another factor that may have contributed to findings of no association is that many studies included patients who were either infected or colonized as potential sources of exposure. Patients with symptomatic infections may shed greater amounts of infectious body fluids to surrounding fomites, compared with patients who are asymptptomatically colonized. Therefore, if a causal association does indeed exist, including both infected and colonized patients as potential sources of exposure may have driven findings toward the null, since exposure to colonized roommates and prior room occupants could present less risk to patients. Heterogeneity of the exposure may have also arisen from variation in the infection or colonization site of a roommate or prior room occupant. In a study of patients with MRSA, environmental contamination was more prevalent on fomites surrounding patients with positive wound or urine cultures, compared with patients who had positive blood or sputum cultures.

The studies we reviewed revealed consistent findings for some pathogens (influenza, group A streptococcus) and inconsistent findings for others (VRE, MRSA, C. difficile). For endemic health care pathogens such as VRE, MRSA, and C. difficile, it may be difficult to isolate the effects of roommates and previous room occupants, since the exposure and outcome are common and may originate from multiple sources. On the contrary, pathogens such as influenza and group A streptococcus are more commonly associated with outbreak scenarios, making it easier to single out the effects of particular exposures. Other factors that may have contributed to inconsistent findings across studies are variations in how exposures and outcomes were defined and operationalized (eg, differences in case definitions, case finding methods, and timing of exposure).

While the inconsistency of findings for some of the organisms could be due to artifact, there may nevertheless be real differences in the effects of roommate and prior room occupant exposure based on the biologic characteristics of the infecting species. Microorganisms vary in their abilities to produce spores and survive changes to atmospheric temperature and moisture conditions. In addition, some organisms favor specific sites of colonization or infection that may produce greater shedding of infectious material and higher potential for environmental contamination. For example, a study of multidrug-resistant pathogens found that environmental contamination was more common surrounding patients with gram-positive versus gram-negative infections. Furthermore, organism species differ in their resiliency to withstand cleaning agents and methods.

The preponderance of evidence presented in this review suggests that there is a link between exposure to infected or colonized roommates and previous room occupants and the risk of HAIs. These findings present a number of practice and policy implications. First, the fact that patient rooms may serve as a reservoir for pathogens deposited by roommates and previous occupants highlights the importance of proper hand hygiene, not just for staff but for competent patients and their visitors as well. To underscore this point, a molecular typing study demonstrated that 12% of patients who became newly colonized with MRSA while in the intensive care unit acquired a strain that most probably came from contamination in their immediate environment. Second, these results emphasize the need for improved cleaning and disinfection of patient rooms, both during patients’ hospital stays and upon their discharge. For patients with known infection or colonization, targeted daily and terminal cleaning procedures that are tailored to specific organisms may reduce environmental contamination and infection rates. Enhancement of routine cleaning measures should not be limited to patients with known infection or colonization, however, since patients may contaminate their environments during incubation periods before the infections are detected or when colonization is not detected through active surveillance.

There were some limitations to this systematic review. It is possible that some studies which would have met the inclusion criteria were not identified. Only databases indexed in PubMed were included, so any unpublished reports and other gray literature would not have been detected by our search. Similarly, studies that found significant positive associations may have been more likely to appear in the literature due to publication bias. Our restriction to articles published in English may have also excluded some relevant papers. While a major strength of this study is its coverage of two and a half decades of literature, changes in the epidemiology of HAIs, infection control policies and procedures, and study methodology over time may have introduced some variability to the studies we reviewed. Lastly, we were unable to conduct a meta-analysis or provide a funnel plot because the studies assessed a wide variety of outcomes.
Table 3 Summary and quality assessment of studies reporting associations between health care-associated infection and exposure to infected or colonized prior room occupants

| Author, quality score | Study period | Setting | Design | Subjects | N |
|-----------------------|--------------|---------|--------|----------|---|
| Ajao et al45          | September 2001–June 2009 | Medical and surgical ICUs in University of Maryland Medical Center | Retrospective cohort | All pts ≥18 years w/o ESBL at hospital admission, neg ESBL screen at ICU admission, and ICU stay ≥48 h | 9,371 admissions (7,651 unique pts) |
| Bass et al46          | March 2010–October 2010 | 34-bed hematology–oncology ward in 427-bed tertiary care teaching hospital, Melbourne, Australia | Quasi-experimental | All pts w/neg VRE rectal swab upon admission and no known history of VRE | 439 pts |
| Chang and Nelson42    | March 1987–August 1987 | 305-bed community hospital, Baltimore, MD | Retrospective cohort | All pts w/LOS >48 h | 2,859 pts |
| Datta et al43         | September 2003–April 2005 and September 2006–April 2008 | ICUs in 750-bed academic medical center | Quasi-experimental | All pts w/neg MRSA and/or VRE screening culture prior to ICU admission | MRSA: 16,345 pts (7,629 baseline, 8,716 intervention); VRE: 16,630 pts (7,806 baseline, 8,824 intervention) |
| Drees et al47         | February 2002–March 2003 | Medical and surgical ICUs, Tufts-New England Medical Center, Boston, MA | Prospective interventional crossover | All pts in ICU ≥48 h w/neg VRE screens within first 48 h of ICU admission and no known history of VRE | 638 pts |
| Huang et al48         | September 2003–April 2005 | Eight adult ICUs, Brigham and Women’s Hospital, Boston, MA | Retrospective cohort | All pts w/o pos MRSA or VRE surveillance cultures within 2 days of ICU admission | MRSA: 7,629 pts; VRE: 7,806 pts |
| Nseir et al49         | December 2006–December 2007 | 30-bed medical/surgical ICU | Prospective cohort | All pts in ICU ≥48 h w/neg MDR GNB screen at admission | 511 pts |
| Shaughnessy et al46   | January 2005–June 2006 | 20-bed ICU in 809-bed tertiary care hospital | Retrospective cohort | All pts w/o Clostridium difficile diagnosis in previous 3 months | 1,770 pts |

**Abbreviations:** APACHE II, acute physiology and chronic health evaluation II; ESBL, extended-spectrum beta-lactamase–producing organism; GLM, generalized linear mixed model; GNB, Gram-negative bacteria; HR, hazard ratio; ICU, intensive care unit; LOD, logistic organ dysfunction score; LOS, length of stay; MDR, multidrug resistant; MRSA, methicillin-resistant Staphylococcus aureus; neg, negative; OR, odds ratio; pts, patients; pos, positive; RR, relative risk; SAPS II, simplified acute physiology score II; VRE, vancomycin-resistant enterococci; w/, with; w/o, without.
### Table 3

**Summary and quality assessment of studies reporting associations between health care-associated infection and exposure**

| Outcome | Exposure | Analysis | Results |
|---------|----------|----------|---------|
| Acquisition of ESBL-producing pathogen during ICU stay detected by clinical or surveillance culture | Immediate prior room occupant w/pos clinical or surveillance ESBL culture | Logistic regression adjusted for colonization pressure, renal disease, anti-MRSA, and anti-pseudomonal beta-lactam therapies | Unadjusted OR: 1.9 (1.3–2.7); adjusted OR: 1.4 (0.9–2.1) |
| Incident VRE colonization detected by rectal surveillance culture | Prior bed occupant w/ VRE colonization or infection | Cox proportional hazard adjusted for roommate status and study intervention phase | HR: 0.4 (0.1–1.2) |
| Incident *C. difficile* diarrhea >48 h after admission and within 15 days of discharge | Prior room occupant w/ *C. difficile* or roommate with prior *C. difficile* infection who is no longer symptomatic | Unadjusted RR | RR: 1.2 (0.3–3.4) |
| Incident MRSA or VRE acquisition | Prior room occupant | GLM adjusted for age, sex, pre-ICU LOS, prior occupant LOS, duration of room vacancy, clustering by ward, diabetes, end-stage renal and liver diseases, malignancies, immunocompromised status | MRSA: baseline OR: 1.4 (p=0.04), intervention OR: 1.1 (p=0.66); VRE: baseline OR: 1.4 (p=0.02), intervention OR: 1.4 (p=0.04) |
| Acquisition of VRE during ICU stay detected by surveillance culture | Prior room occupant (immediate and within previous 2 weeks) | HR adjusting for average colonization pressure and mean antibiotics per day | Immediate prior occupant HR: 3.8 (2.0–7.4); prior occupant within 2 weeks HR: 2.7 (1.4–5.3) |
| Acquisition of MRSA or VRE | Prior room occupant w/ MRSA or VRE colonization or infection | GLM accounting for clustering within ICUs and controlling for age, sex, LOS before ICU admission, prior occupant LOS, duration of room vacancy before occupancy, diabetes, end-stage renal and liver diseases, noncancer immunocompromised state, and malignancies | MRSA OR: 1.4 (1.0–1.8); VRE OR: 1.4 (1.0–1.9) |
| Acquisition of *Pseudomonas aeruginosa* resistant to ceftazidime or imipenem, *Acinetobacter baumannii*, or ESBL-producing GNB | Prior room occupant w/pos MDR GNB screening or diagnostic culture | Logistic regression: MDR *P. aeruginosa* model adjusted for age, SAPS II, LOD, transfer from other wards, LOS prior to ICU admission, prior antibiotics, room occupancy rate, central venous, arterial, and urinary catheters, tracheostomy, sedation, percentage of days in the ICU with amoxicillin–clavulanate acid, piperacillin–tazobactam, fourth-generation cephalosporins, carbapenems, fluoroquinolones, aminoglycosides, mechanical ventilation, and LOS in ICU; A. baumannii model adjusted for SAPS II, LOD, admission type, prior antibiotics, colonization pressure, central venous, arterial and, urinary catheters, sedation, percentage of days in ICU with piperacillin–tazobactam, fourth-generation cephalosporins, and fluoroquinolones | MDR *P. aeruginosa* OR: 2.3 (1.2–4.3); A. baumannii OR: 4.2 (2.0–8.8); ESBL-producing GNB OR: 1.5 (0.6–3.5) |
| Note: multivariable results not reported |
| Incident *C. difficile* infection >48 h after ICU admission and within 30 days of ICU discharge | Immediate prior room occupant w/history of pos *C. difficile* toxin results within 30 days prior to current occupant’s ICU admission | Adjusted HR controlling for age, APACHE II, proton pump inhibitor, and exposure to antibiotics | HR: 2.4 (1.2–4.5) |
Findings of studies investigating the association between health care-associated infection or colonization and exposure to infected or colonized prior room occupants.

Notes: Studies reporting significant positive associations are represented in black circles. Studies that did not find statistically significant associations are represented in gray circles. No studies reported a significant negative association. Circles display study authors, setting, investigation of endemic versus epidemic pathogen, and quality score.

- **Acinetobacter baumannii**
  - Chang and Nelson
  - Acute care, endemic, 94%
- **Clostridium difficile**
  - Shaughnessy et al
  - Acute care, endemic, 94%
- **Extended spectrum beta-lactamase-producing Gram-negative bacteria**
  - Ajao et al
  - Acute care, endemic, 94%
- **Methicillin-resistant Staphylococcus aureus**
  - Nseir et al
  - Acute care, endemic, 89%
  - Drees et al
  - Acute care, endemic, 78%
- **Vancomycin-resistant enterococci**
  - Nseir et al
  - Acute care, endemic, 89%
  - Bass et al
  - Acute care, endemic, 83%
  - Huang et al
  - Acute care, endemic, 94%

Notwithstanding these limitations, it is notable that the studies which reported significant findings were conducted across a range of institutions in several different countries across multiple decades. Presumably, the diverse study facilities employed a variety of cleaning products, methods, and infection control policies. Despite possible variations in practice, exposure to roommates and prior room occupants may have played a role in infection outcomes. Several gaps in the literature remain, however, specifically with regard to organisms that are endemic in health care settings and, therefore, difficult to associate with specific sources of exposure. The use of molecular typing would provide more definitive evidence concerning the role of roommates and prior room occupants in the epidemiology of HAIs.

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**Disclosure**

The authors report no conflicts of interest in this work.

**References**

1. Haley RW, Shachtman RH. The emergence of infection surveillance and control programs in US hospitals: an assessment, 1976. *Am J Epidemiol*. 1980;111(5):574–591.
2. Klevens RM, Edwards JR, Richards CL Jr, et al. Estimating health care-associated infections and deaths in U.S. hospitals, 2002. *Public Health Rep*. 2007;122(2):160–166.
3. Scott RD II; Centers for Disease Control and Prevention. The direct medical costs of healthcare-associated infections in U.S. hospitals and the benefits of prevention. Available from: http://www.cdc.gov/hai/pdfs/hai/scott_costpaper.pdf. Accessed October 1, 2015.
4. Magill SS, Edwards JR, Bamberg W, et al. Multistate point-prevalence survey of health care-associated infections. *N Engl J Med*. 2014;370(13):1198–1208.
5. Weber DJ, Rutala WA, Miller MB, Hulske K, Sickbert-Bennett E. Role of hospital surfaces in the transmission of emerging health care-associated pathogens: norovirus, *Clostridium difficile*, and *Acinetobacter* species. *Am J Infect Control*. 2010;38(5 Suppl 1):S25–S33.
6. Weber DJ, Rutala WA. Understanding and preventing transmission of healthcare-associated pathogens due to the contaminated hospital environment. *Infect Control Hosp Epidemiol*. 2013;34(5):449–452.

7. Duckro AN, Blom DW, Lyle EA, Weinstein RA, Hayden MK. Transfer of vancomycin-resistant enterococci via health care worker hands. *Arch Intern Med*. 2005;165(3):302–307.

8. Boyce JM, Potter-Bayne G, Chenevert C, King T. Environmental contamination due to methicillin-resistant *Staphylococcus aureus*: possible infection control implications. *Infect Control Hosp Epidemiol*. 1997;18(9):622–627.

9. Sitzlar B, Deshpande A, Fertelli D, Kundrapu S, Sethi AK, Donnelly CJ. An environmental disinfection odyssey: evaluation of sequential interventions to improve disinfection of *Clostridium difficile* isolation rooms. *Infect Control Hosp Epidemiol*. 2013;34(5):459–465.

10. Wilson AP, Smyth D, Moore G, et al. The impact of enhanced cleaning within the intensive care unit on contamination of the near-patient environment with hospital pathogens: a randomized crossover study in critical care units in two hospitals. *Crit Care Med*. 2011;39(4):561–568.

11. Ray AJ, Hoyen CK, Taub TF, Eckstein EC, Donnelly CJ. Nosocomial transmission of vancomycin-resistant enterococci from surfaces. *JAMA*. 2002;287(11):1400–1401.

12. Creamer E, Humphreys H. The contribution of beds to healthcare-associated infection: the importance of adequate decontamination. *J Hosp Infect*. 2008;69(1):8–23.

13. Hardy KJ, Oppenheim BA, Gossain S, Gao F, Hawkey PM. A study of the relationship between environmental contamination with methicillin-resistant *Staphylococcus aureus* (MRSA) and patients’ acquisition of MRSA. *Infect Control Hosp Epidemiol*. 2006;27(2):127–132.

14. Giannini MA, Nance D, McCullers JA. Are toilet seats a vector for transmission of methicillin-resistant *Staphylococcus aureus*? *Am J Infect Control*. 2009;37(6):505–506.

15. Guerrero DM, Carling PC, Jury LA, Ponnada S, Nerandzic MM, Donnelly CJ. Beyond the Hawthorne effect: reduction of *Clostridium difficile* environmental contamination through active intervention to improve cleaning practices. *Infect Control Hosp Epidemiol*. 2013;34(5):524–526.

16. Carling PC, Briggs J, Hylander D, Perkins J. An evaluation of patient area cleaning in 3 hospitals using a novel targeting methodology. *Am J Infect Control*. 2006;34(8):513–519.

17. Carling PC. Evaluating the thoroughness of environmental cleaning in hospitals. *J Hosp Infect*. 2008;68(3):273–274.

18. Attaway HH 3rd, Fairey S, Steed LL, Salgado CD, Michels HT, Schmidt MG. Intrinsic bacterial burden associated with intensive care unit hospital bed: effects of disinfection on population recovery and mitigation of potential infection risk. *Am J Infect Control*. 2012;40(10):907–912.

19. Hess AS, Sharrell M, Johnson JK, et al. A randomized controlled trial of enhanced cleaning to reduce contamination of healthcare worker gowns and gloves with multidrug-resistant bacteria. *Infect Control Hosp Epidemiol*. 2013;34(5):487–493.

20. Bhalla A, Pultz NJ, Gries DM, et al. Acquisition of nosocomial pathogens on hands after contact with environmental surfaces near hospitalized patients. *Infect Control Hosp Epidemiol*. 2004;25(2):164–167.

21. Dancer SJ. Hospital cleaning in the 21st century. *Eur J Clin Microbiol Infect Dis*. 2011;30(12):1473–1481.

22. Lemmen SW, Häfner H, Zolldann D, Stanzel S, Lütticken R. Distribution of multi-resistant gram-negative versus gram-positive bacteria in the hospital inanimate environment. *J Hosp Infect*. 2004;56(3):191–197.

23. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *JAMA*. 2004;297(15):126–129.
46. Dancer SJ. Mopping up hospital infection. *J Hosp Infect*. 1999;43(2):85–100.

47. Otter JA, French GL. Survival of nosocomial bacteria and spores on surfaces and inactivation by hydrogen peroxide vapour. *J Clin Microbiol*. 2008;47(1):205–207.

48. Weinstein RA, Hota B. Contamination, disinfection, and cross-colonization: are hospital surfaces reservoirs for nosocomial infection? *Clin Infect Dis*. 2004;39(8):1182–1189.

49. Morgan DJ, Rogawski E, Thom KA, et al. Transfer of multidrug-resistant bacteria to healthcare workers’ gloves and gowns after patient contact increases with environmental contamination. *Crit Care Med*. 2012;40(4):1045–1051.

50. Manian FA, Griesnauer S, Bryant A. Implementation of hospital-wide enhanced terminal cleaning of targeted patient rooms and its impact on endemic *Clostridium difficile* infection rates. *Am J Infect Control*. 2013;41(6):537–541.