Multidrug-resistant Organisms in Hospitals: What Is on Patient Hands and in Their Rooms?

Lona Mody,1,2 Laraine L. Washer,3-4 Keith S. Kaye,5 Kristen Gibson,6 Sanjay Saint,5,6 Katherine Reyes,7 Marco Cassone,1 Julia Manley,1 Jie Cao,1 Sarah Altamimi,1 Mary Perri,1 Hugo Sax,1 Vineet Chopra,3,6 and Marcus Zervos7

1Department of Internal Medicine, Division of Geriatric and Palliative Medicine, University of Michigan Medical School, 2Geriatrics Research Education and Clinical Center, Veterans Affairs Ann Arbor Healthcare System, 3Department of Infection Prevention and Epidemiology, Michigan Medicine, 4Department of Internal Medicine, Division of Infectious Diseases, University of Michigan Health System, 5Patient Safety Enhancement Program and Center for Clinical Management Research, Veterans Affairs Ann Arbor Healthcare System, and 6Division of Hospital Medicine, Department of Medicine, University of Michigan Health System, Ann Arbor, and 7Division of Infectious Diseases and Hospital Epidemiology, University Hospital Zurich, University of Zurich, Switzerland

Background. The impact of healthcare personnel hand contamination in multidrug-resistant organism (MDRO) transmission is important and well studied; however, the role of patient hand contamination needs to be characterized further.

Methods. Patients from 2 hospitals in southeast Michigan were recruited within 24 hours of arrival to their room and followed prospectively using microbial surveillance of nares, dominant hand, and 6 high-touch environmental surfaces. Sampling was performed on admission, days 3 and 7, and weekly until discharge. Paired samples of methicillin-resistant Staphylococcus aureus (MRSA) isolated from the patients’ hand and room surfaces were evaluated for relatedness using pulsed-field gel electrophoresis and staphylococcal cassette chromosome mec, and Panton-Valentine leukocidin typing.

Results. A total of 399 patients (mean age, 60.8 years; 49% male) were enrolled and followed for 710 visits. Fourteen percent (n = 56/399) of patients were colonized with an MDRO at baseline; 10% (40/399) had an MDRO on their hands. Twenty-nine percent of patients harbored an MDRO. Six percent (14/225 patients with at least 2 visits) newly acquired an MDRO on their hands during their stay. New MDRO acquisition in patients occurred at a rate of 24.6/1000 patient-days, and in rooms at a rate of 58.6/1000 patient-days. Typing demonstrated a high correlation between MRSA on patient hands and room surfaces.

Conclusions. Our data suggest that patient hand contamination with MDROs is common and correlates with contamination on high-touch room surfaces. Patient hand hygiene protocols should be considered to reduce transmission of pathogens and healthcare-associated infections.

Keywords. acute care hospitals; multidrug-resistant organisms; colonization; contamination; new acquisition.

Healthcare-associated infections are common, costly, and potentially lethal [1]. Appropriate hand hygiene for healthcare personnel (HCP) is widely recognized as an important approach for preventing infections in hospitalized patients [2, 3]. However, the importance of patient hand hygiene has been recognized only recently [4–7]. Early evidence suggests that this is a missed opportunity for infection reduction and prevention [7]. For example, in a US study of 100 hospitalized patients, 39% of patients’ hands were contaminated with pathogens at ≧48 hours after admission [6]. Another recent study from post–acute care facilities reported that 1 in 4 recently hospitalized patients had at least 1 multidrug-resistant organism (MDRO) on their hands, suggesting that patient hand contamination with MDROs is common [7].

High-touch surfaces in patient rooms, such as bed controls, call buttons, and bedside tray tables, represent a critically important MDRO reservoir [8, 9]. MDROs, including vancomycin-resistant enterococci (VRE), methicillin-resistant Staphylococcus aureus (MRSA), and resistant gram-negative bacilli (RGNB), are frequently shed by patients and staff, whereupon they contaminate surfaces for days, increasing the risk of acquisition by other patients, visitors, and hospital staff that come in contact with these surfaces [9–13].

Compared to other anatomic sites, patients’ hands are likely to come in contact with high-touch surfaces, HCP, visitors, and other patients, increasing the risk of pathogen transmission. Therefore, we sought to characterize MDRO contamination on patients’ hands and the high-touch surfaces in their rooms in hospital settings. The main objectives were to determine (1) the prevalence of MDROs on patients’ hands and in their rooms within the first 24 hours of room arrival; (2) the rate of new acquisition of MDROs on patients’ hands and on the high-touch surfaces in their rooms; and (3) the similarity between patients’ hand contamination and high-touch room surface contamination. This information is necessary for the development,
evaluation, and implementation of effective patient hand hygiene programs in hospitals.

METHODS

Study Population and Design
This study, conducted between February and July 2017, was an observational, prospective cohort study targeting newly admitted hospitalized patients (within 24 hours of arrival to their room). General medicine patients at 2 hospitals in southeast Michigan were enrolled and followed prospectively to evaluate baseline colonization, high-touch surface contamination, and new acquisition of MDROs. The study was approved by the institutional review boards at both institutions. Informed consent to collect surveillance samples and patient-specific data were obtained from each patient or their durable power of attorney.

The inclusion criteria included any patient: (1) newly admitted to participating hospital units—that is, general medicine floors (within 24 hours of admission to their room); and (2) at least 18 years of age. Exclusion criteria included any patient (1) under observation status, generally after a procedure; (2) transferred from another hospital; (3) with cystic fibrosis (due to their high likelihood of MDRO colonization); (4) receiving end-of-life care; (5) non-English speaking; or (6) transferred from an intensive care unit. If an enrolled patient was moved to a new room on a nonparticipating floor, he or she was discharged from the study.

Data Collection
Chart reviews were conducted and data collection sheets completed by trained research staff at each study visit on admission, hospital days 3 and 7, and weekly thereafter. A visit was defined as a patient interaction where clinical data and cultures from the patient and the patient's room were collected. Baseline demographic data were obtained from the patient's admission documentation, including age, sex, height, weight, race, admitting location, history of MDROs, admission diagnosis, Charlson comorbidity score [14], and dependence in activities of daily living (ADL) score [15, 16]. In addition to medical records, patient history of MDRO presence was obtained from clinical laboratory results within the past 90 days. Clinical data collected at each visit included diagnostic testing results (urine, sputum, blood, and wound cultures obtained during hospitalization), presence of an infection, antibiotic use, device use, presence of an open wound(s), and use of isolation precautions. Clinical infection was defined as the presence of infection by physician documentation and receipt of oral or parenteral systemic antibiotics. At the time of study discharge, we documented the discharge disposition as (1) discharged home; (2) discharged to skilled nursing facility; (3) discharged to another unit; (4) discharged at the patient's or family's request; or (5) other disposition, including hospice care or leaving the hospital against medical advice. Both hospitals have comprehensive infection prevention programs (Supplementary Materials).

Microbiologic Methods
Trained research staff swabbed the palm, fingers, and around nails of the dominant hand of enrolled patients, as well as the interior of the nares of both nostrils [7]. Samples were also collected from 6 high-touch surfaces in the patients' rooms: (1) bed control/bed rail; (2) call button/television remote; (3) bedside tray table top; (4) phone; (5) toilet seat; and (6) bathroom door knob. If roommates were enrolled and cultured on the same day (n = 10 visits), the toilet seat and bathroom door knob samples were collected once. Hospital A personnel also obtained perianal cultures from a subset of patients to correlate MDRO colonization with clinical cultures. Microbiological samples were collected at study enrollment (within 24 hours of the patient's arrival to their room), day 3, day 7, and weekly until hospital discharge, at which time a discharge set of cultures was obtained when possible. Premoistened Culturette swabs (Remel, Lenexa, Kansas) were used to obtain the high-touch room surface samples, applying the swab to a 5- × 20-cm area of each site. All samples were tested using standard microbiological methods by the research team. Enrolled patients were not cohorted based on study findings.

Additionally, we were interested in uncovering whether MRSA strains on patient hands were related to those found in the patient's room at the same visit. Thus, we performed molecular typing on patient hand and room surface MRSA isolates from both hospitals using pulsed-field gel electrophoresis (PFGE) and polymerase chain reaction (PCR)-based typing (for additional details, see Supplementary Materials) [17–20].

Statistical Analyses
The main outcomes of interest were baseline prevalence and incidence rates of acquisition of MDROs on patients' hands and on high-touch room surfaces. To assess MDRO presence on patient recruitment, data from all patients were used (n = 399; Supplementary Materials) [21, 22]. To estimate the incidence of MDRO acquisition during hospitalization, the analysis was limited to patients with at least 2 study visits (n = 225). To define new acquisition (per 1000 patient-days), we excluded patients colonized at baseline enrollment with that organism. For example, to define new MRSA acquisition, we excluded patients who were colonized with MRSA at enrollment. To define rates of new MDRO acquisition, we excluded patients colonized at enrollment with all 3 MDROs. At each patient or room surface site, we counted at-risk days from the baseline visit to the first visit in which we found a resistant pathogen or until the discharge visit. Data were analyzed using SAS version 9.4 (SAS Institute, Cary, North Carolina) and Stata version 13.0 (StataCorp, College Station, Texas) software.
RESULTS

Baseline Characteristics
A total of 399 of 524 (76%) eligible patients were enrolled and followed for 710 visits (flowchart, Supplementary Figure 1). The baseline demographics of the patients are shown in Table 1. The mean age was 60.8 years (standard deviation, 16.8 years). Forty-nine percent were male; 64.4% identified as white and 25.3% identified as African American. A majority (80.5%) of patients had at least 1 comorbidity at baseline and 25% were dependent in at least 1 ADL. Baseline characteristics among patients dependent in at least 1 ADL vs patients completely independent are shown in Supplementary Table 1. There were no deaths among our subjects during the study period.

Patient and Room Surface Contamination With MDRO at Enrollment
Fourteen percent (56/399) of patients were colonized with an MDRO at baseline. Ten percent (40/399) had an MDRO on their hands, 7.5% (30/399) in their nares, and 3.5% (14/399) on both. Among those colonized with an MDRO, 57% (32/56) harbored MRSA, 36% (20/56) RGNB, and 14% (8/56) VRE. Perianal cultures were obtained from 41 patients at hospital A at the time of study enrollment; 7% (n = 3) of patients cultured at the perianal area were positive for VRE and 7% (n = 3) were positive for RGNB. Of the 56 patients colonized with an MDRO at enrollment, 11 (20%) had a history of MDRO colonization or infection (5 of whom were colonized with the same MDRO he or she had a reported history of—ie, 4 with MRSA, 1 with RGNB).

Twenty-nine percent (n = 115) of the sampled surfaces of patient rooms were contaminated with an MDRO at baseline (Figure 1). Fifteen percent of these surfaces were contaminated with RGNB, 8.5% with MRSA, and 8% with VRE. Hospitals A and B varied with regard to the types of MDROs identified. The most prevalent MDROs at hospital A were VRE (11%, n = 22), followed by MRSA (8%) and RGNB (1.5%); the most prevalent MDROs at hospital B were RGNB (29%, n = 57), followed by MRSA (9%) and VRE (5%). See Supplementary Table 2 for the most common RGNBs found on enrolled patients and room surfaces.

Hand Carriage of MDROs at Enrollment and During Follow-up
At baseline, 10% of patients’ dominant hands were contaminated with an MDRO; 5% with MRSA, 3.5% with RGNB, and 2% with VRE. Of the 5% (n = 20 patients) with MRSA contamination on the hand, 10 (50%) were concurrently colonized at the nares. MRSA contamination at baseline remained present in 6 (30%) patients and transient in 14 (70%) patients. An additional 6.2% (n = 14) of 225 patients with a follow-up visit acquired a new MDRO on their hands (Figure 1). Of interest, we observed a stepwise increase in MDRO contamination in patients and room surfaces as the number of hours in the room prior to enrollment and baseline sampling increased (Figure 2).

We were particularly interested in correlation between clinical infection and colonization with an MDRO on patients’ anatomic sites, in particular their dominant hands. Six study patients had an MRSA-positive clinical culture (3 wounds, 1 blood, 1 urine, and 1 sputum) during the study. Of these, MRSA was detected either from the patient’s sample or the room sample 100% of the time (4/6 patient dominant hands, 2/6 patient nares, 1/6 patient hand and nares, 4/6 patient room). No VRE was detected in clinical cultures. Of the 84 total perianal cultures collected from 42 patients at hospital A, no colonization results correlated with clinical culture results.

To estimate the patient acquisition rates of a new MDRO, the analysis included 225 patients with >1 study visit (148 at hospital A, 77 at hospital B) (536 total sampling visits). At hospital A, 10.1% (n = 15/148) of patients acquired an MDRO during follow-up, for a rate of 29.0/1000 patient-days. At hospital B, 7.8% (n = 6/77) of patients acquired an MDRO during follow-up, for a rate of 17.8/1000 patient-days. The median time to new colonization with MRSA, VRE, or RGNB was 11, 7, and 3 days, respectively (Supplementary Figure 2).

Similarity Between Patient Hand Contamination and Room Surface Contamination
The room surfaces of patients were contaminated with MRSA, RGNB, and VRE at 9.2%, 13.2%, and 9.7% of visits, respectively. Patient hands were colonized with MRSA at 5% of the sampling study visits, RGNB at 3.0%, and VRE at 2.5% of visits. In 10% (73/710) of sampling visits, patients and their room surfaces were concurrently colonized with an MDRO (ie, patient and environment samples were positive for the same MDRO on the same sampling visit). Hand contamination with MRSA and VRE were each associated with contamination of the patient’s high-touch room surfaces by the same organism (Table 3). For example, of 35 visits where patient hands were colonized with MRSA, 71.4% of patient rooms were also contaminated with MRSA (Table 3). MRSA was not detected in the patient’s room in 94.1% of visits when MRSA was not found on hands (P < .001). To confirm this finding, we typed 118 MRSA isolates from all 25 visits where MRSA was recovered from both the patient’s dominant hand and at least 1 room surface at the same visit. At hospital A, all 15 visits (n = 9 patients) showed matching MRSA strains (290% in 14 visits, 86% in 1 visit using Dice criteria for PFGE and PCR typing [19]) between the hand sample and at least 1 environmental site. At hospital B, 9 of the 10 visits (n = 7 patients) showed matching MRSA strains (100% similarity). One such case in which the same MRSA strain was on the patient and in the patient’s room is shown in Supplementary Figure 3. The single visit that did not show 100% similarity between MRSA strains included a USA300 from both the patient hand and room surface at enrollment and a USA800 on the patient hand at a subsequent visit.

DISCUSSION
For more than a century, hand hygiene research, resources, and promotion have almost exclusively focused on improving HCP
Table 1. Baseline Characteristics of Patients

| Characteristic                        | All Patients (N = 399) | Hospital A (n = 200) | Hospital B (n = 199) |
|---------------------------------------|------------------------|----------------------|----------------------|
| Age, mean, y (SD)                    | 60.8 (16.8)            | 58.7 (16.2)          | 63.0 (17.2)          |
| Sex, male                            | 195 (48.9)             | 98 (49.0)            | 97 (48.7)            |
| Race                                  |                        |                      |                      |
| White                                 | 257 (64.4)             | 173 (86.5)           | 84 (42.2)            |
| African American                      | 101 (25.3)             | 15 (7.5)             | 86 (43.2)            |
| Admitted from                         |                        |                      |                      |
| Home                                  | 385 (96.5)             | 188 (94.0)           | 190 (95.5)           |
| Urgent care/clinic                    | 49 (12.3)              | 42 (21.0)            | 7 (3.5)              |
| ED transfer                           | 16 (4.0)               | 15 (7.5)             | 1 (0.5)              |
| Outpatient                            | 3 (0.8)                | 3 (1.5)              | 0 (0)                |
| Home healthcare service               | 1 (0.3)                | 0 (0)                | 1 (0.5)              |
| Nursing home/assisted living          | 13 (3.3)               | 11 (5.5)             | 9 (4.5)              |
| Homeless shelter                      | 1 (0.3)                | 1 (0.5)              | 0 (0)                |
| Days of study follow-up, mean (SD)    | 2.3 (3.0)              | 3.5 (3.8)            | 1.0 (0.1)            |
| No. of study visits, mean (SD)        | 1.8 (0.9)              | 2.1 (0.9)            | 1.5 (0.7)            |
| Reason for study discharge            |                        |                      |                      |
| Discharged home                       | 322 (80.7)             | 152 (76.0)           | 170 (85.4)           |
| Discharged to subacute rehab/SNF      | 34 (8.5)               | 25 (12.5)            | 9 (4.5)              |
| Discharged to another unit            | 31 (7.8)               | 15 (7.5)             | 16 (8.0)             |
| At patient or family request          | 5 (1.3)                | 3 (1.5)              | 2 (1.0)              |
| Other (hospice or left AMA)           | 7 (1.8)                | 5 (2.5)              | 2 (1.0)              |
| Shared room                           | 229 (57.4)             | 137 (68.5)           | 92 (46.2)            |
| History of MDRO (in past 90 d)        | 28 (7.0)               | 25 (12.5)            | 3 (1.5)              |
| MRSA                                  | 9 (2.3)                | 8 (4.0)              | 1 (0.5)              |
| RGMB                                  | 18 (4.5)               | 17 (8.5)             | 1 (0.5)              |
| VRE                                   | 4 (1.0)                | 3 (1.5)              | 1 (0.5)              |
| Any comorbidity                       | 321 (80.5)             | 167 (83.5)           | 154 (77.4)           |
| ADL, No. (%) dependent                |                        |                      |                      |
| Bathing                               | 76 (19.0)              | 55 (27.5)            | 21 (10.6)            |
| Dressing                              | 70 (17.5)              | 50 (25.0)            | 20 (10.1)            |
| Toileting                             | 61 (15.3)              | 43 (21.5)            | 18 (9.0)             |
| Transferring                          | 89 (22.3)              | 66 (33.0)            | 23 (11.6)            |
| Continence                            | 41 (10.3)              | 31 (15.5)            | 10 (5.0)             |
| Feeding                               | 18 (4.5)               | 8 (4.0)              | 10 (5.0)             |
| ≥1 ADLs dependent                     | 101 (25.3)             | 73 (36.5)            | 28 (14.1)            |
| Present at enrollment:                |                        |                      |                      |
| Any infection                         | 117 (29.3)             | 82 (41.0)            | 35 (17.6)            |
| SSTI                                  | 38 (9.5)               | 27 (13.5)            | 11 (5.5)             |
| UTI                                   | 26 (6.5)               | 20 (10.0)            | 6 (3.0)              |
| Pneumonia                             | 26 (6.5)               | 20 (10.0)            | 6 (3.0)              |
| Antibiotic use                        | 170 (42.6)             | 107 (53.5)           | 63 (31.7)            |
| Device use                            | 68 (17.0)              | 46 (23.0)            | 22 (11.1)            |
| Urinary catheter                      | 13 (3.3)               | 8 (4.0)              | 5 (2.5)              |
| Nephrostomy tube                      | 2 (0.5)                | 1 (0.5)              | 1 (0.5)              |
| Feeding tube                          | 12 (3.0)               | 9 (4.5)              | 3 (1.5)              |
| Central venous catheter               | 34 (8.5)               | 23 (11.5)            | 11 (5.5)             |
| Dialysis catheter                     | 16 (4.0)               | 13 (6.5)             | 3 (1.5)              |
| Open wound(s)                         | 51 (12.8)              | 37 (18.5)            | 14 (7.0)             |
| Contact precautions                   | 36 (9.0)               | 32 (16.0)            | 4 (2.0)              |

Data are presented as no. (%) unless otherwise specified.

Abbreviations: ADL, activities of daily living; AMA, against medical advice; ED, emergency department; MDRO, multidrug-resistant organism; MRSA, methicillin-resistant Staphylococcus aureus; RGMB, resistant gram-negative bacteria; SD, standard deviation; SNF, skilled nursing facility; SSTI, skin and soft tissue infection; UTI, urinary tract infection; VRE, vancomycin-resistant enterococci.
hand hygiene [23, 24]. These efforts have included efficient, safer, and more effective cleansing products, innovative educational delivery models, materials, and training, as well as auditing strategies. With contemporary patients allotting substantial time toward interactions and procedures inside and outside their rooms, pathogen transfer between the environment and patient hands is likely and yet understudied. In this prospective cohort study, conducted in 2 different hospitals with diverse patient populations, we show that 10% of patient hands were colonized with an MDRO at enrollment, 29% of rooms were contaminated within 24 hours of admission, and patient hand contamination was associated with patient room contamination with the same MDRO. Furthermore, 6.2% of patient hands and 21.8% of rooms newly acquired an MDRO during the hospital stay.

Numerous studies show that on average, about 5% of HCP hands are contaminated with an MDRO [25–27], the most common being MRSA, VRE, and RGNB, such as *Acinetobacter* species and *Pseudomonas aeruginosa* [27]. Research on patient hand contamination by pathogens is now emerging [6, 7, 21, 28–31]. Hedin and colleagues, using a fingerprinting method, showed that *Escherichia coli*, *Klebsiella* species, enterococci, and *S. aureus* were commonly found on patient hands in a Swedish hospital during an outbreak with enteric pathogens [31]. Cao et al swabbed the dominant hands of 357 post–acute care patients newly admitted to nursing facilities and showed that 24% of this high-risk group had an MDRO on admission and an additional 10% acquired a new MDRO during their stay [7]. Cross-transmission with the environment was evident in a follow-up study showing that when post–acute care patients’ hands are culture-positive for an MDRO, their environment is often contaminated with the same MDRO [21, 28].

Our study advances this literature now in hospitals [32] by showing that the rates of patient hand contamination with an MDRO on admission to a hospital are high and new acquisition is frequent, perhaps surpassing that of HCP [25, 26]. In emerging healthcare systems where there is emphasis for early mobility, financial penalties for adverse events related to immobility and falls, and frequent treatment or procedures out of the room, patient hand contamination can have significant implications on MDRO transmission with both near and far environmental surfaces.

Furthermore, we show that one-third of the patient rooms were contaminated with an MDRO on the day of admission, with contamination evident in patients recruited within the first 8 hours of room occupancy, suggesting that patients were often admitted with an MDRO and that there was a rapid change in

![Figure 1](image-url). Percentage of patient hand contamination and room surface contamination with multidrug-resistant organisms (MDROs). Patient hand contamination (left 3 columns) and patient room contamination (right 3 columns) were calculated at baseline, follow-up visits, and any time during follow-up. The table underneath indicates the raw numbers represented in the figure. *A patient can be colonized with 1 MDRO at baseline and be at risk to acquire another MDRO.
microbial milieu in patients’ rooms after admission. This was most pronounced in patients with a clinical culture that was positive for MRSA, where a majority of MRSA-infected patients also harbored MRSA on their hands. Future projects should explore how often patients come to the emergency room from the community with an MDRO, or any potential new MDRO acquisition by patients when being evaluated within our emergency rooms or when receiving their diagnostic workup from the emergency room. We show that hand contamination with MRSA, VRE, and RGNB is associated with high-touch room surface contamination with the same organism, suggesting active transmission with strain match approaching 100% between MRSA on patient hands and their room surfaces. Whether patient hand hygiene interventions and enhanced patient engagement can reduce environmental contamination, MDRO transmission, and nosocomial infections merits further evaluation [33–36]. Our observations suggest that at the minimum, patient hand hygiene programs should be targeted to MRSA-infected patients as an additional infection prevention strategy.

We note a few limitations. First, although we recruited nearly 400 patients and conducted >700 visits, our sample is a fraction of all patients admitted to a hospital. Second, we obtained perianal cultures from a subset of patients to see if they predict clinical infection better than hand contamination. Future studies could obtain multianatomic site samples to further explore this question. Third, we did not perform high-touch surface cultures prior to room occupancy as recruitment occurred once patients were admitted to their rooms. Fourth, we cannot ascertain whether a patient contaminated the high-touch room surfaces or whether pathogens were introduced by HCPs. Finally, our study does not address patient-to-patient transmission of pathogens, which remains a critical gap in MDRO transmission literature [37] and will be explored in subsequent projects. Although MRSA strains were deemed similar using both PFGE and PCR criteria, future studies should define the degree of similarity and timing of divergence using advanced genomic methods.

Limitations notwithstanding, our study also has strengths. First, this prospective cohort study was conducted in 2 different hospitals, serving very different and diverse populations. Second, we repeated the sampling over multiple follow-up visits from the same patients, allowing us to characterize new acquisition rates at the patient level. Finally, we are the first to correlate patient hand contamination with high-touch room surface contamination in hospital settings using both traditional microbiologic and advanced molecular methods. This research is important to demonstrate similarity between patient hand and environmental contamination to then design future patient hand hygiene interventions that would reduce both.

While the burden of preventing infections has largely been borne by HCPs, our study shows that patient hands are an important reservoir and play a crucial role in the transmission of pathogens in acute care hospitals. Thus, patient hand hygiene protocols should be implemented and tested for their ability to reduce environmental contamination, pathogen transmission, and healthcare-associated infections as well as to increase meaningful patient engagement in infection prevention.

**Supplementary Data**

Supplementary materials are available at *Clinical Infectious Diseases* online. Consisting of data provided by the authors to benefit the reader, the posted materials are not copyedited and are the sole responsibility of the authors, so questions or comments should be addressed to the corresponding author.
### Table 2. Incidence Rates (per 1000 Patient-Days) of New Multidrug-resistant Organism Acquisition

| Site                   | MRSA                  | RGNB                  | VRE                  | Any MDRO               |
|------------------------|-----------------------|-----------------------|----------------------|------------------------|
|                        | Hospital A | Hospital B | Total | Hospital A | Hospital B | Total | Hospital A | Hospital B | Total | Hospital A | Hospital B | Total |
| Hand                   | 3/510 (5.9) | 1/318 (3.1) | 4/828 (4.8) | 5/537 (9.3) | 1/327 (3.1) | 6/864 (6.9) | 5/518 (9.7) | 1/338 (3.0) | 6/856 (7.0) | 11/537 (20.5) | 3/338 (8.9) | 14/875 (16.0) |
| Nares                  | 2/498 (4.0) | 0/326 (0.0) | 2/824 (2.4) | 3/560 (5.4) | 4/329 (12.2) | 7/889 (7.9) | 2/561 (3.6) | 0/338 (0.0) | 2/899 (2.2) | 7/548 (12.8) | 4/338 (11.8) | 11/886 (12.4) |
| Hand or nares          | 2/477 (4.2) | 0/315 (0.0) | 2/792 (2.5) | 8/529 (15.1) | 5/320 (15.6) | 13/849 (15.3) | 6/511 (11.7) | 1/338 (3.0) | 7/849 (8.2) | 15/517 (29.0) | 6/338 (17.8) | 21/855 (24.6) |
| Patient’s room         | 11/467 (23.6) | 1/307 (3.3) | 12/774 (15.5) | 8/525 (15.2) | 13/344 (53.3) | 21/769 (27.3) | 2/561 (3.6) | 0/338 (0.0) | 2/899 (2.2) | 35/502 (69.7) | 14/334 (41.9) | 49/836 (58.6) |
| Patient’s body site or room | 12/477 (25.2) | 1/323 (3.1) | 13/800 (16.3) | 14/521 (26.9) | 16/314 (51.0) | 30/835 (35.9) | 5/511 (11.7) | 3/338 (9.0) | 8/849 (9.7) | 39/497 (78.5) | 18/334 (53.9) | 57/831 (68.6) |

Data include 148 patients at hospital A and 77 patients at hospital B with at least 1 follow-up visit.
Abbreviations: MDRO, multidrug-resistant organism; MRSA, methicillin-resistant Staphylococcus aureus; RGNB, resistant gram-negative bacteria; VRE, vancomycin-resistant enterococci.

### Table 3. Association Between Patient Hand Contamination and Room Surface Contamination With Multidrug-resistant Organisms

| Patient Room          | MRSA Contamination | RGNB Contamination | VRE Contamination |
|-----------------------|--------------------|--------------------|-------------------|
|                       | Positive | Negative | Total | P Value | Positive | Negative | Total | P Value | Positive | Negative | Total | P Value |
| All visits (n = 710)  |          |          |       |         |          |          |       |         |          |          |       |         |
| Positive              | 25 (71.4) | 40 (5.9) | 65 (9.2) | < .001 | 11 (52.4) | 83 (12.0) | 94 (13.2) | .003 | 16 (88.9) | 53 (17.7) | 69 (9.7) | < .001 |
| Negative              | 10 (28.6) | 635 (94.1) | 645 (90.8) | … | 10 (47.6) | 606 (88.0) | 616 (86.8) | … | 2 (11.1) | 639 (92.3) | 641 (90.3) | … |
| Total                 | 35 | 675 | 710 | … | 21 | 689 | 710 | … | 18 | 692 | 710 | … |
| Base line visits (n = 399) |          |          |       |         |          |          |       |         |          |          |       |         |
| Positive              | 12 (80.0) | 22 (15.8) | 34 (8.5) | … | 9 (64.3) | 51 (11.2) | 60 (15.0) | .005 | 6 (75.0) | 26 (6.6) | 32 (8.0) | .01 |
| Negative              | 8 (20.0) | 357 (94.2) | 365 (91.5) | … | 5 (35.7) | 334 (86.6) | 339 (85.0) | … | 2 (25.0) | 365 (93.4) | 367 (92.0) | … |
| Total                 | 20 | 379 | 399 | … | 14 | 385 | 399 | … | 8 | 391 | 399 | … |

Abbreviations: MRSA, methicillin-resistant Staphylococcus aureus; RGNB, resistant gram-negative bacteria; VRE, vancomycin-resistant enterococci.
Notes
Acknowledgments. The authors acknowledge invaluable data collection assistance from the research project staff (Lynn Gregory, RN, Shen Dewar, MD, and Helina Misikir, MPH). They thank their collaborators at the Centers for Disease Control and Prevention (CDC) (Nimalie Stone, MD, and Alex Kallen, MD, MPH). They also thank the many patients for their willingness to participate.

Financial support. This study was funded by a contract from the CDC (contract number BAA 200-2016-91954 to L. M.).

Author contributions. L. M. 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: All authors. Acquisition, analysis, or interpretation of data: L. M., K. G., K. R., M. C., J. M., J. C., S. A., M. P. M. Z. Drafting of the manuscript: L. M., L. L. W., K. S. K., K. G., M. C., J. C., M. Z. Critical revision of the manuscript for important intellectual content: All authors. Obtained funding: L. M., L. L. W., K. S. K., S. S. V., C. M. Z. Administrative, technical, or material support: K. G., M. C., J. M., J. C. S., A. M. Study supervision: L. M., L. L. W., K. S. K., K. R., M. Z.

Potential conflicts of interest. K. S. K. reports personal fees from Xenex, outside the submitted work. L. M. and L. L. W. report grants from the National Institutes of Health, outside the submitted work. S. S. reports personal fees from Doximity and Ivon, outside the submitted work. M. Z. reports payments from Genentech and Medimune, outside the submitted work. M. Z. considers relevant to the content of the manuscript have been disclosed.

References
1. Centers for Disease Control and Prevention. 2014 national and state healthcare-associated infections progress report. Available at: www.cdc.gov/hai/progres-report/index.html. Accessed 13 October 2017.
2. Boyle IM, Pittet D; Healthcare Infection Control Practices Advisory Committee. Society for Healthcare Epidemiology of America. Association for Professionals in Infection Control. Infections Diseases Society of America. Hand Hygiene Task Force. Guideline for hand hygiene in health-care settings: recommendations of the Healthcare Infection Control Practices Advisory Committee and the HCPC/Shea/APIC/JDSA hand hygiene task force. Infect Control Hosp Epidemiol 2002; 23:53–40.
3. Pittet D, Allegranti B, Boyce J; World Health Organization World Alliance for Patient Safety First Global Patient Safety Challenge Core Group of Experts. The World Health Organization guidelines on hand hygiene in health care and their appropriate recommendations. Infect Control Hosp Epidemiol 2009; 30:611–22.
4. Landers T, Abusalem S, Coty MB, Bingham J. Patient-centered hand hygiene: the next step in infection prevention. Am J Infect Control 2012; 40:511–7.
5. Kim MK, Nam EY, Na SH, et al. Discrepancy in perceptions regarding patient participation in hand hygiene between patients and health care workers. Am J Infect Control 2015; 43:510–5.
6. Istenes N, Bingham J, Haizlett S, Fleming E, Kirk J. Patients’ potential role in the transmission of health care-associated infections: prevalence of contamination with bacterial pathogens and patient attitudes toward hand hygiene. Am J Infect Control 2013; 41:793–8.
7. Cao J, Min L, Lansiing B, Foxman B, Mody L. Multidrug-resistant organisms on patients’ hands: a missed opportunity. JAMA Intern Med 2016; 176:705–6.
8. Murphy CR, Eells SJ, Quan V, et al. Methicillin-resistant Staphylococcus aureus burden in nursing homes associated with environmental contamination of common areas. J Am Geriatr Soc 2012; 60:1012–8.
9. Dancer SJ. Controlling hospital-acquired infection: focus on the role of the environment and new technologies for decontamination. Clin Microbiol Rev 2014; 27:665–90.
10. Huang SS, Datta R, Platt R. Risk of acquiring antibiotic-resistant bacteria from prior room occupants. Arch Intern Med 2006; 166:1945–51.
11. Drees M, Snyderman DR, Schmid CH, et al. Prior environmental contamination increases the risk of acquisition of vancomycin-resistant enterococci. Clin Infect Dis 2008; 46:678–85.
12. Wilks M, Wilson A, Warwick S, et al. Control of an outbreak of multidrug-resistant Acinetobacter baumannii-calcoaceticus colonization and infection in an intensive care unit (ICU) without closing the ICU or placing patients in isolation. Infect Control Hosp Epidemiol 2006; 27:654–8.
13. Noer S, Blaziejewski C, Lubret R, Wallet F, Courcol D, Durocher A. Risk of acquiring multidrug-resistant gram-negative bacilli from prior room occupants in the intensive care unit. Clin Microbiol Infect 2011; 17:1201–8.
14. Charlson ME, Pompei P, Alex KL, MacKenzie CR. A new method of classifying prognostic comorbidity in longitudinal studies: development and validation. J Chronic Dis 1987; 40:373–83.
15. Katz S, Downs TD, Cash HR, Grotz RC. Progress in development of the index of ADL. Gerontologist 1982; 19:10–20.
16. Katz S. Assessing self-maintenance: activities of daily living, mobility, and instrumental activities of daily living. J Am Geriatr Soc 1983; 31:272–7.
17. Clinical and Laboratory Standards Institute. Performance standards for antimicrobial susceptibility testing. 26th ed. CLSI supplement M100. Wayne, PA: CLSI, 2016.
18. Cassone M, Manley J, Perri MB, et al. Environmental panels as a proxy for nursing facility patients with methicillin-resistant Staphylococcus aureus and vancomycin-resistant Enterococcus colonization. Clin Infect Dis 2018; 67:861–8.
19. Tenero FC, Arbeit RD, Goering RV, et al. Interpreting chromosomal DNA restriction patterns produced by pulsed-field gel electrophoresis: criteria for bacterial strain typing. J Clin Microbiol 1995; 33:2233–9.
20. Lina G, Piémont Y, Godail-Gamot F, et al. Involvement of Panton-Valentine leukocidin-producing Staphylococcus aureus in primary skin infections and pneumonia. Clin Infect Dis 1999; 29:1128–32.
21. Patel PK, Manley J, Mody L. Patient hand colonization with MDROs is associated with environmental contamination in post-acute care. Infect Control Hosp Epidemiol 2017; 38:1110–3.
22. Chow S, Shao J, Wang H. Sample size calculations in clinical research. 2nd ed. Boca Raton, FL: Chapman & Hall/CRC, 2008.
23. Othersen MJ, Othersen HB Jr. A history of hand washing: seven hundred years at a small place. Pharo Alpha Omega Honor Med Soc 1987; 50:23–7.
24. Ellingson K, Haas JP, Aiello AE, et al. Society for Healthcare Epidemiology of America (SHEA). Strategies to prevent healthcare-associated infections through hand hygiene. Infect Control Hosp Epidemiol 2014; 35:937–60.
25. Colburn NE, Cadnium J, Flannery E, Chang S, Donskey CJ, Stiefel U. Perception vs reality: methicillin-resistant Staphylococcus aureus carriage among healthcare workers at a Veterans Affairs Medical Center. Infect Control Hosp Epidemiol 2016; 37:110–2.
26. Ferring YH, Clock SA, Wong-Mcloughlin J, et al. Multicenter study of hand carriage of potential pathogens by neonatal ICU healthcare personnel. J Pediatric Infect Dis Soc 2015; 4:276–9.
27. Montoya A, Schildhouse R, Goyal A, et al. How often are healthcare personnel hands colonized with multi-drug resistant organisms? A systematic review and meta-analysis. Am J Infect Control 2018; pii: S0196-6533(18)31031–9. doi:10.1016/j.ajic.2018.10.017. Epub ahead of print.
28. Sunkesula VCK, Kundrapsu S, Knighton S, Cadnium JL, Donskey CJ. A randomized trial to determine the impact of an educational patient-hand hygiene intervention on contamination of hospitalized patient's hands with healthcare-associated pathogens. Infect Control Hosp Epidemiol 2017; 38:595–7.
29. Barker JK, Zellmer C, Tischendorf J, et al. On the hands of patients with Clostridium difficile: a study of spore prevalence and the effect of hand hygiene on C. difficile removal. Am J Infect Control 2017; 45:1315–6.
30. Sunkesula V, Kundrapsu S, Macinga DR, Donskey CJ. Efficacy of alcohol gel for removal of methicillin-resistant Staphylococcus aureus from hands of colonized patients. Infect Control Hosp Epidemiol 2015; 36:229–31.
31. Hedin G, Blomkvist A, Janson M, Lindblom A. Occurrence of potentially pathogenic bacteria on the hands of hospital patients before and after the introduction of patient hand disinfection. AMJIS 2012; 120:802–7.
32. Otter JA, Yezi S, Salkeld JA, French GL. Evidence that contaminated surfaces contribute to the transmission of hospital pathogens and an overview of strategies to address contaminated surfaces in hospital settings. Am J Infect Control 2013; 41:56–11.
33. Srigley JA, Furness CD, Garmen M. Interventions to improve patient hand hygiene: a systematic review. J Hosp Infect 2016; 94:23–9.
34. Haverstick S, Goodrich C, Freeman R, James S, Kullar R, Ahrens M. Patients’ hand washing and reducing hospital-acquired infection. Crit Care Nurse 2017; 37:e1–8.
35. Pokrywka M, Buraczewski M, Frank D, et al. Can improving patient hand hygiene impact Clostridium difficile infection events at an academic medical center? Am J Infect Control 2017; 45:959–63.
36. Cheng VCC, Wong SC, Wong IYW, et al. The challenge of patient empowerment in hand hygiene promotion in health care facilities in Hong Kong. Am J Infect Control 2017; 45:562–5.
37. Wolfsenberger A, Slack L, Kuster SP, et al. Transfer of pathogens to and from patients, healthcare providers, and medical devices during care activity—a systematic review and meta-analysis. Infect Control Hosp Epidemiol 2018; 39:1093–107.