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Transmission of Resistant Gram-Negative Bacteria to Health Care Worker Gowns and Gloves during Care of Nursing Home Residents in Veterans Affairs Community Living Centers

Natalia Blanco,[a] Lisa Pineles,[a] Alison D. Lydecker,[a,b] J. Kristie Johnson,[a,c] John D. Sorkin,[b,d] Daniel J. Morgan,[a,b] the VA Gown and Glove Investigators, Mary-Claire Roghmann,[a,b] for the CDC Prevention Epicenters Program

Department of Epidemiology and Public Health, University of Maryland School of Medicine, Baltimore, Maryland, USA[a]; VA Maryland Health Care System, Baltimore, Maryland, USA[b]; Department of Pathology, University of Maryland School of Medicine, Baltimore, Maryland, USA[c]; Claude D. Pepper Older Americans Independence Center, University of Maryland School of Medicine, Baltimore, Maryland, USA[d]

ABSTRACT The objectives of the study were to estimate the risk of transmission of antibiotic-resistant Gram-negative bacteria (RGNB) to gowns and gloves (G&G) worn by health care workers (HCWs) when providing care to nursing home residents and to identify the types of care and resident characteristics associated with transmission. A multicenter, prospective observational study was conducted with residents and HCWs from Veterans Affairs (VA) nursing homes. Perianal swabs to detect RGNB were collected from residents. HCWs wore G&G during usual care activities, and the G&G were swabbed at the end of the interaction in a standardized manner. Transmission of RGNB from a colonized resident to G&G by type of care was measured. Odds ratios (ORs) associated with type of care or resident characteristics were estimated. Fifty-seven (31%) of 185 enrolled residents were colonized with ≥1 RGNB. RGNB transmission to HCW gloves or gowns occurred during 9% of the interactions ($n = 905$): 7% to only gloves and 2% to only gowns. Bathing the resident and providing hygiene and toilet assistance were associated with a high risk of transmission. Glucose monitoring and assistance with feeding or medication were associated with a low risk of transmission. In addition, antibiotic use by the resident was strongly associated with greater transmission (OR, 2.51; $P < 0.01$). RGNB were transferred to HCWs during ~9% of visits. High-risk types of care were identified for which use of G&G may be prioritized. Antibiotic use was associated with 2.5 times greater risk of transmission, emphasizing the importance of antibiotic stewardship. (This study has been registered at ClinicalTrials.gov under registration no. NCT01350479.)

KEYWORDS antibiotic resistance, Gram-negative bacteria, nursing homes, transmission

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Address correspondence to Mary-Claire Roghmann, mroghmann@som.umaryland.edu.

Multidrug-resistant organisms (MDROs), including resistant Gram-negative bacteria (RGNB), are increasingly common causes of colonization and infection in long-term-care facilities (1–6). Up to 40% of nursing home residents are colonized with RGNB (2, 5, 7), which can be spread from patient to patient by health care workers (HCWs) (8–10).

Patient isolation or contact precautions, including the use of gowns and gloves, are recommended and frequently used to prevent MDRO transmission in acute-care settings. In contrast, in long-term-care facilities, there is significant variation in the steps taken when a resident is known to be colonized or infected with MDROs (11). Until recently, few evidence-based guidelines have described best practices to prevent the transmission of MDROs in nursing homes.

Our group recently reported that transmission of methicillin-resistant *Staphylococcus aureus* (MRSA) from colonized residents to HCW gloves and gowns (20% and 11%, respectively) occurs frequently (12). Transmission varied by type of care, which allowed us to identify high-risk types of care (e.g., changing wound dressings, dressing and bathing the resident, and assisting with hygiene) where use of gowns and gloves would significantly decrease transmission rates without unduly increasing the burden of caring for residents without stigmatizing them (12).

With the aim of providing data that would be helpful in the development of evidence-based guidelines for the care of residents of long-term-care facilities who are colonized or infected with RGNB, we examined care-specific transmission of RGNB to HCW gowns and gloves. In addition, we aimed to identify resident characteristics associated with transmission of RGNB.

RESULTS

Resident characteristics. From 203 enrolled residents, a perianal swab was collected from 185 residents (91%) (Table 1). Enrolled residents with or without an available perianal swab were similar with regard to age, sex, assistance needs, antibiotic use, and most devices. Among the 185 swabbed residents, 57 (31%) were colonized with RGNB. Thirty-two (56%) of these 57 residents were colonized with only 1 resistant isolate, whereas 44% of residents were colonized with $>$1 RGNB. We observed significantly different perianal colonization rates among the nursing homes ($P < 0.01$): nursing home A, 13.3%; B, 7.7%; C, 57.1%; D, 33.3; E, 78.8%.

Microbiological characteristics. A total of 86 RGNB were isolated from the residents' perianal swabs, of which 81 (94%) belonged to the *Enterobacteriaceae* family, represented mostly by *Escherichia coli* and *Proteus mirabilis*. The remaining isolates were *Acinetobacter baumannii* ($n = 4$) and *Pseudomonas aeruginosa* ($n = 1$). Among the 81 isolates from the *Enterobacteriaceae* family, 81 (100%) were resistant to ciprofloxacin, 17 (21%) were resistant to ceftazidime, and 18 (22%) were resistant to imipenem. Among the *A. baumannii* isolates, all were resistant to ciprofloxacin and ceftazidime, and none were resistant to imipenem. The 1 *P. aeruginosa* isolate was resistant to ciprofloxacin and imipenem. Similarly, among the 86 resistant isolates, 56 (65%) were resistant to only one of the analyzed antibiotics, whereas 35% were resistant to two or more antibiotics.

Gown and glove transmission with RGNB by type of care. We observed a median of 17 (interquartile range, 12 to 21) interactions per RGNB-colonized resident. Overall, either gowns or gloves were contaminated with RGNB during 9% (7% gloves, 2% gowns) of 905 interactions with RGNB-colonized residents. Probability of transmission of RGNB to HCW gowns or gloves was not significantly associated with nursing home site (data not shown). Seventy-one percent of the interactions had only one type of care during the interaction, 13% had two types, 5% had three types, and 12% had four or more types. Types of care were stratified by (i) care that occurred with other care activities and (ii) care that occurred alone. The risk of RGNB transmission to gloves with medication administration was 10% when combined with other types of care and 1% when it was the only type of care. The risk of RGNB transmission to gloves with feeding was 33% when done in conjunction with other types of care and 0% when done alone. None of the other types of care showed a significant difference.

A random sample of 11 residents who were not found to be colonized by RGNB in the perianal culture (157 interactions) were also analyzed, and 4 (36%) of them had HCW interactions positive for RGNB. Of the 157 HCW interactions, 6 (4%) glove swabs and 5 (3%) gown swabs were positive for RGNB.

RGNB transmission from colonized residents to HCWs varied by type of care activity from 0% to 13% for gowns and 0% to 27% for gloves (Fig. 1). Crude rates of transmission by type of care were very close to transmission rates adjusted for repetitive measures by resident (median difference, 1.2% for gloves and 0.2% for gowns). We

TABLE 1 Demographic and clinical characteristics of study population

Characteristic	Overall population (n = 185) (n [%])
Age (yr [range])	69 (29–108)
Sex	
Male	178 (96)
Female	7 (4)
Race/ethnicity	
Asian	1 (1)
Black/African American	64 (36)
White	108 (59)
Native Hawaiian/Other Pacific Islander	7 (4)
Nursing homes by location[a]	
A	90 (48.7)
B	26 (14)
C	21 (11.3)
D	15 (8.1)
E	33 (17.8)
Length of stay in nursing home before enrollment (days [range])	248 (1–6,235)
Need of assistance	145 (86)
Acute-care hospitalization in past 3 mo	49 (27)
Device	
Indwelling urinary catheter	37 (20)
External urinary catheter	10 (5)
Ostomy	14 (8)
Feeding tube	7 (4)
Tracheostomy	5 (3)
PICC line[b]	9 (5)
Dialysis catheter	9 (5)
Any wound	65 (35)
Secretion at enrollment	
Stool incontinence	26 (14)
Diarrhea	9 (5)
Heavy wound secretions	28 (15)
Antibiotic use at enrollment	
Any	45 (24)
Topical	22 (12)
Systemic	27 (15)

[a]Nursing homes were grouped by location and identified as A to E for confidentiality purposes.
[b]PICC, peripherally inserted central catheter.

identified hygiene assistance (brushing teeth, combing hair) and bathing the resident as high-risk activities for gown contamination (OR, >1.0; $P < 0.05$) (Table 2). Glucose monitoring and assistance with medications or feeding were identified as low-risk activities for gown contamination, because no transmission was observed during these types of care. Provision of hygiene, bathing, and toilet assistance, in addition to device care or use, were identified as high-risk activities for glove contamination (OR, >1.0; $P < 0.05$) (Table 2). Glucose monitoring and assistance with medications or feeding were identified as low-risk activities for glove contamination as well (OR, <1.0; $P < 0.05$) (Table 2).

Resident characteristics that increase gown and glove transmission with RGNB. We examined whether resident characteristics, specifically the presence of body secretions, increased the risk of RGNB transmission. Diarrhea, heavy wound secretions, and heavy respiratory secretions were rare in the study population, so we focused on stool incontinence and presence of wounds. In our population, stool incontinence was not statistically associated with transmission of RGNB to HCW gowns (OR, 2.7; $P = 0.12$) or

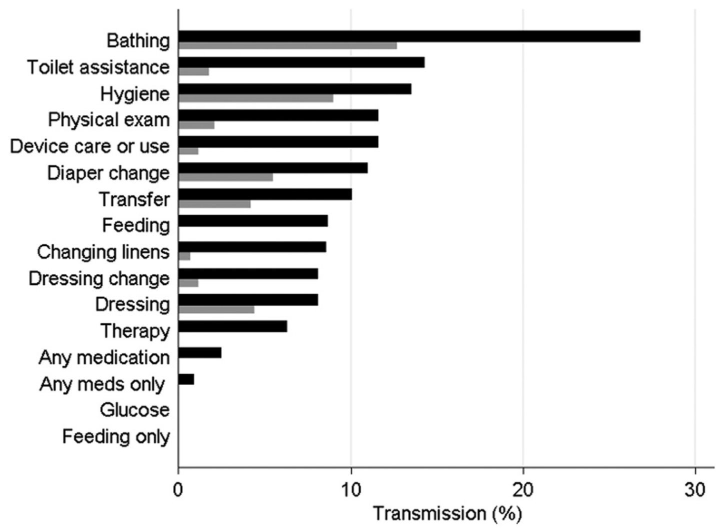

FIG 1 RGNB transmission to HCW gowns and gloves during care of RGNB-colonized residents ($n = 57$) by type of care provided during 905 interactions. Black bars, transmission to gloves; gray bars, transmission to gowns.

gloves (OR, 0.4; $P = 0.19$). Similarly, having a wound was not statistically associated with transmission of RGNB to HCW gowns (OR, 1.47; $P = 0.54$) or gloves (OR, 1.22; $P = 0.63$).

Additionally due to the relationship between antibiotic use and selective colonization pressure (13), we analyzed the association between the residents' antibiotic use at enrollment and transmission risk. Among our colonized residents, 11 (19%) were on antibiotics at the time of enrollment: 6 patients were using topical antibiotics (bacitracin, $n = 4$; mupirocin, $n = 1$; and clindamycin, $n = 1$), and 5 were on systemic antibiotics (amoxicillin-clavulanate, $n = 2$; moxifloxacin, $n = 1$; vancomycin, $n = 1$; and sulfamethoxazole-trimethoprim, $n = 1$). We found that residents who were on any type of antibiotics at enrollment had significantly higher odds of transmission to gowns and gloves (OR, 10.15; $P < 0.01$) than residents who were not on antibiotics at enrollment (OR, 2.51; $P = 0.02$). When stratified by type of antibiotic, systemic or topical, the same positive trend was observed (Table 3).

TABLE 2 Odds ratio of transmission of RGNB to HCW gowns or gloves by type of care given to nursing home resident

			Transmission to[a]:			
			Gloves		Gowns	
Type of care	No. of interactions	Care given with other care (%)	OR	*P* value	OR	*P* value
Bathing	71	83	5.60	<0.01	10.05	<0.01
Toilet assistance	56	80	2.46	0.01	0.76	0.83
Hygiene	111	87	2.22	0.02	7.17	<0.01
Any device care or use	86	56	1.87	0.04	0.45	0.60
Physical exam	95	32	1.75	0.05	1.10	0.89
Transfer of resident	168	72	1.55	0.19	2.35	0.14
Diaper change	145	82	1.48	0.20	0.76	0.03
Dressing change	86	42	1.46	0.25	0.49	0.50
Dressing resident	137	91	1.37	0.37	2.27	0.25
Changing linens	139	42	1.26	0.41	0.25	0.23
Feeding	23	26	0.65	0.74	No transmission	
Any therapy	16	6	0.51	0.73	No transmission	
Any medications	279	19	0.29	<0.01	No transmission	
Any medication alone	227	0	0.12	<0.01	No transmission	
Feeding alone	17	0	No transmission		No transmission	
Glucose monitoring	36	78	No transmission		No transmission	

[a]Odds of transmission divided by odds of transmission if that type of care was not given, calculated using GEE to account for the correlation of repeated measurements obtained from a given resident.

TABLE 3 Odds ratio of transmission of RGNB to HCW gloves or gowns, accounting for use or nonuse of antibiotics by nursing home resident

Antibiotic use at enrollment	Transmission to[a]:			
	Gloves		Gowns	
	OR	*P* value	OR	*P* value
Any	2.51	0.02	10.15	<0.01
Topical	2.82	0.02	3.41	0.07
Systemic	1.54	0.42	7.89	<0.01

[a]Odds of transmission given antibiotic use at enrollment divided by odds given no antibiotic use, calculated using GEE to account for the correlation of repeated measurements obtained from a given resident.

DISCUSSION

Overall, we found that 9% of HCW interactions with VA nursing home residents resulted in the transmission of RGNB to HCW gloves or gowns. Device care or use and assistance with hygiene, toileting, and bathing were identified as high-risk activities for HCW gown and glove contamination. Glucose monitoring and assistance with medications or feeding were identified as low-risk activities. Moreover, resident use of antibiotics increased the risk of transmission to HCW gowns and gloves.

Transmission to gloves was 3 times more common than transmission to gowns, which highlights the importance of hand washing, particularly in the absence of glove use. Furthermore, although we observed lower levels of transmission to gowns, potential contamination of HCW clothes or scrubs in the absence of gown use was demonstrated. This reinforces the importance of creating guidelines to prevent transmission of MDROs to HCW clothes or scrubs that may result in the transmission of RGNB to other nursing home residents.

Surprisingly, we observed transmission of RGNB to HCW gowns or gloves from residents not detected to be colonized by RGNB in the perianal culture. In a previous study in community-based nursing homes, we observed similar levels of MRSA transmission among residents not previously known to be colonized with MRSA (14). Other potential sources of RGNB are other colonized resident body sites that were not swabbed as part of this study (e.g., throat or skin sites) or the environment (15–19). Morgan et al. (16) reported that HCW gowns and gloves are 4 times more likely to be contaminated with MDROs when the patient's room environmental cultures are positive. Likewise, Thurlow et al. (19) demonstrated the need to culture more than one anatomic site (e.g., inguinal skin) to identify all *Klebsiella pneumoniae* carbapenemase-producing *Enterobacteriaceae*–colonized patients.

Our results are consistent with previously published results by our group about MRSA transmission to HCW gowns and gloves from MRSA-colonized residents in the same population. We observed 3 times higher overall transmission of MRSA than RGNB (12). This observed difference may be due to the higher skin concentrations of MRSA versus RGNB (19, 20). However, in previous transmission studies by our group in acute-care settings, higher transmission levels of multiresistant *P. aeruginosa* and *A. baumannii* to HCW gowns and gloves were observed than for MRSA or vancomycin-resistant *Enterococci* (16). Differences in patient severity and the inclusion of infected patients besides those who were colonized may explain the observed differences between results.

Additionally, similar high-risk and low-risk types of care were identified for MRSA and RGNB transmission in these studies. Gram-negative bacteria are more commonly found in the gastrointestinal track (19), which explains why we were able to identify unique high-risk activities associated with RGNB transmission, such as toilet assistance.

The use of antibiotics was identified as a resident characteristic that increased the odds of transmission of RGNB from colonized residents to HCWs. Although biologically plausible, to our knowledge, this is the first report associating antibiotic use and transmission of RGNB in nursing homes. Other authors have associated antibiotic use and incidence of RGNB-associated infections in other settings. Kaier et al. (21) showed a temporal increase of fluoroquinolones and third-generation cephalosporins with an upward incidence of extended-spectrum β-lactamase strains in a time-series analysis. Likewise, Hsueh et al. (22) observed a correlation between certain classes of antibiotics and resistance of Gram-negative bacteria at a university hospital in Taiwan.

The observed association between systemic and topical antibiotic use and higher transmission of RGNB may be explained by the selective colonization pressure exerted by antibiotic use. Selective pressure refers to the inhibition of competing microorganisms by antibiotic therapy, which, in this case, would promote the proliferation of RGNB (13). Antibiotic-associated overgrowth of RGNB contributes to increased shedding of the antibiotic-resistant microorganisms in stool, favoring contamination of the residents' skin or environmental surfaces (13, 23, 24). Higher burden of RGNB on the residents' skin or environmental surfaces may lead to transmission to HCW gowns and gloves (23). Topical antibiotics are often used on wounds in nursing homes; however, we did not detect an association between wounds and transmission, suggesting that the use of antibiotics on wounds was the key. Furthermore, the topical antibiotics used (bacitracin, mupirocin, and clindamycin) have activity against Gram-positive but not Gram-negative bacteria, suggesting a potential overgrowth of RGNB in the wounds. Our results support the importance of antibiotic stewardship, including topical antibiotics, not only to reduce resistant colonization pressure but also to reduce MDRO transmission. However, further studies are needed to confirm this proposed mechanism.

Our study is limited by the fact that our outcome, transmission to HCW gowns and gloves, acts as a surrogate for RGNB transmission to other nursing home residents. We were unable to determine how often contamination of gowns and gloves results in transmission to other HCWs or residents (12). In addition, we did not perform pulsed-field gel electrophoresis to compare the resident strains with the strains isolated from gowns and gloves. However, high (up to 89%) concordance between antibiotic-resistant strains in similar transmission studies was published by our group (14, 16). Although the generalizability of our results may be limited by a veteran population, our study is strengthened by its multisite prospective design, which is representative of the national VA nursing home population (12).

Nursing homes are unique environments that require a balance between infection prevention and a homelike atmosphere, which complicates infection and control practices for MDROs. To our knowledge, we are the first to study RGNB transmission by type of care and resident characteristics in VA nursing homes. This study provides evidence beyond our previously reported study for prevention of MRSA transmission (12), which demonstrates the potential benefit of a care-based or patient-specific nursing home-specific approach to reduce the transmission of MDROs in this setting.

MATERIALS AND METHODS

Study design and population. We present data obtained from glove and gown swabs collected as part of a multicenter, prospective, observational study reporting the frequency of and risk factors for the contamination of HCW gloves and gowns when providing care to VA nursing home residents. We previously reported data describing MRSA transmission in this population (12). This report describes transmission of RGNB in the same cohort. The protocol was approved by the VA Central Institutional Review Board (12).

Residents from seven VA nursing homes in Baltimore, Maryland; Boston, Massachusetts; Buffalo, New York; San Antonio, Texas; and Washington, DC, were approached for enrollment) (12). Nursing homes were grouped by location and identified as A to E for confidentiality purposes. On average, there were 167 (range, 90 to 275) beds per nursing home. The nursing staff-to-resident ratio was consistent across the participating nursing homes. Enrollment details are included in Fig. 2. From 2012 to 2015, eligible residents were enrolled with a written informed consent; HCWs were enrolled with verbal consent.

Data collection. A research coordinator recorded demographic and clinical characteristics and collected a perianal swab from enrolled residents at baseline. For up to 28 days after a resident enrolled in our study, we asked HCWs to wear gowns and gloves during usual care activities. The research coordinator observed and recorded the type of care delivered with each interaction. When the HCWs were finished with their care activities, the coordinator swabbed their gloves and gowns in a standardized manner (12).

Laboratory analysis. Residents' perianal swabs and HCW gown and glove swabs were cultured for pathogenic antibiotic-resistant Gram-negative bacteria at a central research laboratory. Perianal swabs

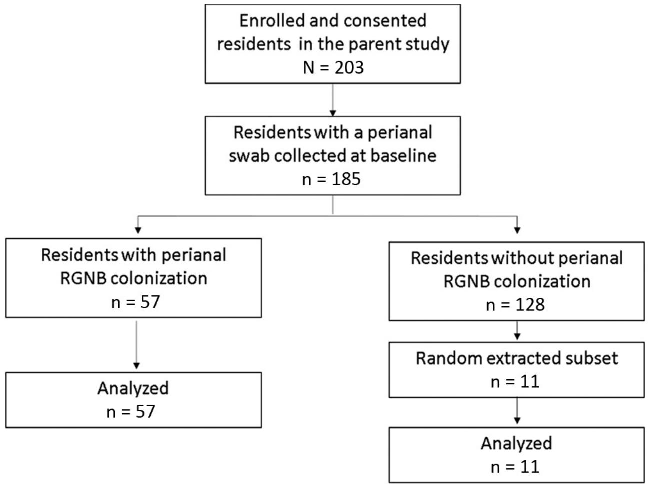

FIG 2 Enrollment diagram.

were rolled onto the surface of each of the following plates: MacConkey agar supplemented with 1 μg/ml of ciprofloxacin, MacConkey agar supplemented with 1 μg/ml of ceftazidime, and MacConkey agar supplemented with 1 μg/ml of imipenem. Plates were streaked for isolation and incubated aerobically at 37°C for 24 h. Identification was confirmed using the Vitek II system (bioMérieux, Inc., Hazelwood, MO, USA). The Kirby-Bauer test was used to confirm each organism's susceptibility to antibiotics. Organisms were categorized as susceptible, intermediate, or resistant based on the Clinical and Laboratory Standards Institute's (CLSI) breakpoints (25).

Study definitions. For the purposes of this study, RGNB were defined as any pathogenic Gram-negative bacteria categorized as intermediate or resistant based on the Kirby-Bauer test for at least one of the following antibiotics: ciprofloxacin, ceftazidime, or imipenem. Residents were considered colonized with RGNB if their perianal culture was positive for at least one RGNB.

Transmission to gowns and/or gloves with RGNB was deemed to occur when at least one strain isolated from the HCW gowns or gloves matched the genus, species, and antibiotic resistance pattern of the strain isolated from the respective RGNB-colonized resident. For example, if the resident was colonized with ciprofloxacin-resistant *E. coli*, transmission was deemed to have occurred if ciprofloxacin-resistant *E. coli* was isolated from the HCW gowns or gloves after interacting with this resident.

Statistical analysis. Resident characteristics were described using proportions for categorical variables and medians and ranges for continuous variables. Overall crude transmission rate was estimated as the number of HCW interactions that led to RGNB transmission over the total number of HCW interactions. Overall transmission rates to HCW gowns or gloves, gloves only, and gowns only were estimated. Additionally, the crude rate of transmission by type of care was estimated as the total number of HCW interactions that led to transmission during a particular type of care over the total number of HCW interactions of this particular type of care. The transmission rate by type of care was compared with the rate estimated via Poisson regression, in which generalized estimating equations (GEE) were used to account for the serial autocorrelation of repeated observations obtained from the same resident (26). Additionally, because resident-HCW interactions could include more than one type of care, we compared the risk of RGNB transmission for each type of care when it was given with another type of care to the risk when the type of care was given alone. When the risk of transmission was importantly different (the risk went from high to low), we separated the type of care into care given with other types of care and care given alone. Logistic regression, using GEE to account for the correlation of repeated measures, was used to estimate the odds ratio (OR) associated with each type of care and specific resident characteristics. The OR gives the odds of RGNB transmission to HCW gloves or gowns when a resident receives a particular type of care divided by the odds of RGNB transmission when the resident receives care other than the particular type of care being examined. An OR of $>$1.0 associated with a P value of $<$0.05 for specific types of care or resident characteristics was considered high risk.

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REFERENCES

1. Yoshikawa TT. 2002. Antimicrobial resistance and aging: beginning of the end of the antibiotic era? J Am Geriatr Soc 50:S226–S229.
2. Mody L, Bradley SF, Strausbaugh LJ, Muder RR. 2001. Prevalence of ceftriaxone- and ceftazidime-resistant Gram-negative bacteria in long-term-care facilities. Infect Control Hosp Epidemiol 22:193–194. https://doi.org/10.1086/503397.
3. Pop-Vicas AE, D'Agata EM. 2005. The rising influx of multidrug-resistant gram-negative bacilli into a tertiary care hospital. Clin Infect Dis 40: 1792–1798. https://doi.org/10.1086/430314.
4. Lee DC, Barlas D, Ryan JG, Ward MF, Sama AE, Farber BF. 2002. Methicillin-resistant Staphylococcus aureus and vancomycin-resistant enterococci: prevalence and predictors of colonization in patients presenting to the emergency department from nursing homes. J Am Geriatr Soc 50:1463–1465.
5. Trick WE, Weinstein RA, DeMarais PL, Kuehnert MJ, Tomaska W, Nathan C, Rice TW, McAllister SK, Carson LA, Jarvis WR. 2001. Colonization of skilled-care facility residents with antimicrobial-resistant pathogens. J Am Geriatr Soc 49:270–276. https://doi.org/10.1046/j.1532-5415.2001.4930270.x.
6. Siegel JD, Rhinehart E, Jackson M, Chiarello L, Health Care Infection Control Practices Advisory Committee. 2007. 2007 Guideline for isolation precautions: preventing transmission of infectious agents in health care settings. Am J Infect Control 35:S65–164. https://doi.org/10.1016/j.ajic.2007.10.007.
7. Dommeti P, Wang L, Flannery EL, Symons K, Mody L. 2011. Patterns of ciprofloxacin-resistant gram-negative bacteria colonization in nursing home residents. Infect Control Hosp Epidemiol 32:177–180. https://doi.org/10.1086/657946.
8. Harris AD, Perencevich EN, Johnson JK, Paterson DL, Morris JG, Strauss SM, Johnson JA. 2007. Patient-to-patient transmission is important in extended-spectrum beta-lactamase-producing Klebsiella pneumoniae acquisition. Clin Infect Dis 45:1347–1350. https://doi.org/10.1086/522657.
9. Johnson JK, Smith G, Lee MS, Venezia RA, Stine OC, Nataro JP, Hsiao W, Harris AD. 2009. The role of patient-to-patient transmission in the acquisition of imipenem-resistant Pseudomonas aeruginosa colonization in the intensive care unit. J Infect Dis 200:900–905. https://doi.org/10.1086/605408.
10. Harris AD, Kotetishvili M, Shurland S, Johnson JA, Morris JG, Nemoy LL, Johnson JK. 2007. How important is patient-to-patient transmission in extended-spectrum beta-lactamase Escherichia coli acquisition. Am J Infect Control 35:97–101. https://doi.org/10.1016/j.ajic.2006.09.011.
11. Smith PW, Bennett G, Bradley S, Drinka P, Lautenbach E, Marx J, Mody L, Nicolle L, Stevenson KSHEA, APIC. 2008. SHEA/APIC guideline: infection prevention and control in the long-term care facility, July 2008. Infect Control Hosp Epidemiol 29:785–814. https://doi.org/10.1086/592416.
12. Pineles L, Morgan DJ, Lydecker A, Johnson JK, Sorkin JD, Langenberg P, Blanco N, Lesse A, Sellick J, Gupta K, Leykum L, Cadena J, Lepcha N, Roghmann MC. 2017. Transmission of methicillin-resistant *Staphylococcus aureus* to health care worker gowns and gloves during care of residents in Veterans Affairs nursing homes. Am J Infect Control pii: S0196-6553(17)30200-30206. https://doi.org/10.1016/j.ajic.2017.03.004.
13. Donskey CJ. 2006. Antibiotic regimens and intestinal colonization with antibiotic-resistant Gram-negative bacilli. Clin Infect Dis 43:S62–S69. https://doi.org/10.1086/504481.
14. Roghmann MC, Johnson JK, Sorkin JD, Langenberg P, Lydecker A, Sorace B, Levy L, Mody L. 2015. Transmission of methicillin-resistant staphylococcus aureus (MRSA) to healthcare worker gowns and gloves during care of nursing home residents. Infect Control Hosp Epidemiol 36: 1050–1057. https://doi.org/10.1017/ice.2015.119.
15. Lemmen SW, Hafner H, Zolldann D, Stanzel S, Lutticken R. 2004. Distribution of multi-resistant Gram-negative versus Gram-positive bacteria in the hospital inanimate environment. J Hosp Infect 56:191–197. https://doi.org/10.1016/j.jhin.2003.12.004.
16. Morgan DJ, Rogawski E, Thom KA, Johnson JK, Perencevich EN, Shardell M, Leekha S, Harris AD. 2012. Transfer of multidrug-resistant bacteria to healthcare workers' gloves and gowns after patient contact increases with environmental contamination. Crit Care Med 40:1045–1051. https://doi.org/10.1097/CCM.0b013e31823bc7c8.
17. Filius PM, Gyssens IC, Kershof IM, Roovers PJ, Ott A, Vulto AG, Verbrugh HA, Endtz HP. 2005. Colonization and resistance dynamics of Gram-negative bacteria in patients during and after hospitalization. Antimicrob Agents Chemother 49:2879–2886. https://doi.org/10.1128/AAC.49.7.2879-2886.2005.
18. Weintrob AC, Roediger MP, Barber M, Summers A, Fieberg AM, Dunn J, Seldon V, Leach F, Huang XZ, Nikolich MP, Wortmann GW. 2010. Natural history of colonization with Gram-negative multidrug-resistant organisms among hospitalized patients. Infect Control Hosp Epidemiol 31: 330–337. https://doi.org/10.1086/651304.
19. Thurlow CJ, Prabaker K, Lin MY, Lolans K, Weinstein RA, Hayden MK, Centers for Disease Control and Prevention Epicenters Program. 2013. Anatomic sites of patient colonization and environmental contamination with Klebsiella pneumoniae carbapenemase-producing Enterobacteriaceae at long-term acute care hospitals. Infect Control Hosp Epidemiol 34:56–61. https://doi.org/10.1086/668783.
20. Oie S, Suenaga S, Sawa A, Kamiya A. 2007. Association between isolation sites of methicillin-resistant Staphylococcus aureus (MRSA) in patients with MRSA-positive body sites and MRSA contamination in their surrounding environmental surfaces. Jpn J Infect Dis 60:367–369.
21. Kaier K, Frank U, Hagist C, Conrad A, Meyer E. 2009. The impact of antimicrobial drug consumption and alcohol-based hand rub use on the emergence and spread of extended-spectrum beta-lactamase-producing strains: a time-series analysis. J Antimicrob Chemother 63:609–614. https://doi.org/10.1093/jac/dkn534.
22. Hsueh PR, Chen WH, Luh KT. 2005. Relationships between antimicrobial use and antimicrobial resistance in Gram-negative bacteria causing nosocomial infections from 1991-2003 at a university hospital in Taiwan. Int J Antimicrob Agents 26:463–472. https://doi.org/10.1016/j.ijantimicag.2005.08.016.
23. Donskey CJ. 2004. The role of the intestinal tract as a reservoir and source for transmission of nosocomial pathogens. Clin Infect Dis 39: 219–226. https://doi.org/10.1086/422002.
24. Donskey CJ, Chowdhry TK, Hecker MT, Hoyen CK, Hanrahan JA, Hujer AM, Hutton-Thomas RA, Whalen CC, Bonomo RA, Rice LB. 2000. Effect of antibiotic therapy on the density of vancomycin-resistant enterococci in the stool of colonized patients. N Engl J Med 343:1925–1932. https://doi.org/10.1056/NEJM200012283432604.
25. Clinical and Laboratory Standards Institute. 2017. Performance standards for antimicrobial susceptibility testing. Clinical and Laboratory Standards Institute, Wayne, PA.
26. Liang K, Zeger SL. 1986. Longitudinal data analysis using generalized linear models. Biometrika 73:13–22. https://doi.org/10.1093/biomet/73.1.13.