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MAJOR ARTICLE

Containment of a Verona Integron-Encoded Metallo-Beta-Lactamase-Producing *Pseudomonas aeruginosa* Outbreak Associated With an Acute Care Hospital Sink—Tennessee, 2018–2020

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Background. Contaminated healthcare facility wastewater plumbing is recognized as a source of carbapenemase-producing organism transmission. In August 2019, the Tennessee Department of Health (TDH) identified a patient colonized with Verona integron-encoded metallo-beta-lactamase-producing carbapenem-resistant *Pseudomonas aeruginosa* (VIM-CRPA). A record review revealed that 33% (4 of 12) of all reported patients in Tennessee with VIM had history of prior admission to acute care hospital (ACH) A intensive care unit (ICU) Room X, prompting further investigation.

Methods. A case was defined as polymerase chain reaction detection of bla_{VIM} in a patient with prior admission to ACH A from November 2017 to November 2020. The TDH performed point prevalence surveys, discharge screening, onsite observations, and environmental testing at ACH A. The VIM-CRPA isolates underwent whole-genome sequencing (WGS).

Results. In a screening of 44% ($n = 11$) of 25 patients admitted to Room X between January and June 2020, we identified 36% ($n = 4$) colonized with VIM-CRPA, resulting in 8 cases associated with Room X from March 2018 to June 2020. No additional cases were identified in 2 point-prevalence surveys of the ACH A ICU. Samples from the bathroom and handwashing sink drains in Room X grew VIM-CRPA; all available case and environmental isolates were found to be ST253 harboring $bla_{VIM\text{-}1}$ and to be closely related by WGS. Transmission ended after implementation of intensive water management and infection control interventions.

Conclusions. A single ICU room's contaminated drains were associated with 8 VIM-CRPA cases over a 2-year period. This outbreak highlights the need to include wastewater plumbing in hospital water management plans to mitigate the risk of transmission of antibiotic-resistant organisms to patients.

Keywords. carbapenem-resistant; carbapenemase; healthcare-associated infections; opportunistic pathogens of premise plumbing; outbreak.

Multidrug-resistant (MDR) *Pseudomonas aeruginosa* is an emerging pathogen listed as a "serious threat" in the Centers for Disease Control and Prevention (CDC) 2019 Antibiotic Resistance Threats Report [1]. *Pseudomonas aeruginosa* is considered an opportunistic pathogen of premise plumbing, capable of forming persistent biofilms in hospital water systems [2]. Contaminated plumbing has been linked to numerous outbreaks of Gram-negative bacilli, including MDR-*P. aeruginosa* [3–9]. In addition to intrafacility transmission from contaminated plumbing, interfacility patient sharing may propagate the regional spread of resistant strains [10, 11].

Within the United States, approximately 2%–3% of carbapenem-resistant *P. aeruginosa* harbor mobile genetic elements that encode carbapenemase enzymes, which inactivate carbapenems and most other β-lactam antibiotics [1]. These mobile genetic elements can transfer horizontally between bacteria, including across species, contributing to the rapid spread of

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carbapenem resistance [1]. The most frequently identified carbapenemase among *P. aeruginosa* worldwide and in the United States is Verona integron-encoded metallo-beta-lactamase (VIM) [12]. From 2017–2021, 682 VIM-carbapenem-resistant *P. aeruginosa* (CRPA) were identified among 56,016 isolates tested in the United States (https://arpsp.cdc.gov/profile/arln/crpa).

To contain the spread of multidrug-resistant pathogens, the Tennessee Department of Health (TDH) investigates all reported cases of VIM-producing organisms. For each case investigated, epidemiological data are collected, via REDCap, such as demographic and history of previous healthcare, including locations and dates of admission. In this study, we describe a multifacility outbreak of VIM-CRPA linked to sink drains in a single room (Room X) of an intensive care unit (ICU) in acute care hospital A (ACH A).

METHODS

Outbreak Identification and Case Finding

Beginning in 2017, Tennessee (TN) State Public Health Laboratory (SPHL) and TDH asked clinical laboratories to voluntarily submit patient information and isolates of CRPA for carbapenemase gene testing. From November 2017 to August 2022, the TN SPHL identified a total of 20 VIM-CRPA among approximately 15,200 isolates and colonization swabs tested. In March 2019, SPHL detected bla_{VIM} by polymerase chain reaction (PCR) on a rectal swab collected as part of a local long-term acute care hospital (LTACH A)'s admission screening protocol for carbapenemase-producing organisms (CPOs). The bacterial organism harboring bla_{VIM} was nonviable for culture, preventing further identification. Chart reviews revealed that this patient also had CRPA cultured from urine collected in February 2019, although the isolate did not undergo testing to determine the mechanism of carbapenem resistance and the patient did not have a history of other CPOs. The patient had been directly admitted to LTACH A after a 12-day stay in the ACH A's ICU. The TDH conducted a point prevalence survey (PPS) of patients in the ICU at ACH A in April 2019; no additional patients with bla_{VIM} were identified via the Cepheid Carba-R (Cepheid, Sunnyvale, CA). In August 2019, TDH was notified of another VIM-CRPA isolated from a rectal swab collected on admission screening to LTACH A after a 19-day stay in the ACH A's ICU. An August 2019, a PPS conducted in the ACH A ICU did not identify additional isolates carrying bla_{VIM}. Further review of medical records for both patients revealed that both had been admitted to the same room within the ICU of ACH A (Room X).

For the purposes of this investigation, a case was defined as any patient specimen positive for bla_{VIM} using a PCR-based test and with a history of admission to ACH A during or after November 2017, when TN's first VIM case was identified. A retrospective review of all detected VIM in TN identified an additional 2 cases with specimen collection dates of March and September 2018; both were found to have been admitted to Room X during their hospitalizations. Due to this information, TDH recommended that all patients admitted to Room X be placed on empiric Contact Precautions and undergo CPO rectal screening at time of discharge to identify any new cases.

Infection Prevention and Control Assessments and Facility Interventions

The TDH assessed infection control practices onsite at ACH A's ICU, with a focus on Room X, in August 2019, February 2020, and June 2020. Visits included observations of clinical care and interviews with healthcare providers (HCPs). Onsite observations and feedback focused on practices related to water and plumbing use (eg, faucet and drain orientation, cleaning and disinfection practices for patient environments). We asked HCPs about practices related to premise plumbing, such as frequency of hand hygiene at different ICU sinks, storage of clean care items within a sink's splash radius, and use of sinks for disposal of enteral feedings and other nutritive substances that may contribute to biofilm formation and proliferation. A summary of findings and recommendations were provided to ACH A infection preventionists after each visit.

Environmental and Water Testing

During the February 2020 visit, TDH collected water, drain, and aerator samples from the handwashing and bathroom sinks from Room X, a second ICU room (Room Y, where no known cases were admitted), and a hallway handwashing sink. For each sink, 1 liter of postflush, blended water was collected using a sterile container containing sodium thiosulfate. Dual swab collection devices (COPAN Italia Spa., Brescia, Italy) were used to collect samples from the top 1 inch of sink drains and faucet aerators [13]. The SPHL tested the water and swab samples for *P. aeruginosa* using Pseudosel selective and differential media. For isolates identified as *P. aeruginosa*, the modified carbapenem inactivation method (mCIM) was used to detect carbapenemase production [14]. The mCIM-positive isolates were subsequently tested for the bla_{VIM} gene using an in-house SPHL PCR assay. Comprehensive methods on laboratory testing performed on environmental and patient isolates are provided in Supplementary Files 1 and 2.

Whole-Genome Sequencing

The VIM-CRPA isolates from cases and *P. aeruginosa* isolates from environmental samples underwent whole-genome sequencing (WGS) at the SPHL. Libraries were prepared with Illumina Nextera XT Library Prep Kit and sequenced on the Illumina MiSeq. The WGS data were analyzed at the Florida Department of Health, Bureau of Public Health Laboratories in Jacksonville, Florida. Comprehensive methods on WGS performed on the case and environmental isolates are provided in Supplementary File 3.

Patient Consent Statement

The patients screened in this investigation provided consent that met requirements for each healthcare facility's internal consent policy. As part of public health surveillance activities, this study was exempt from Institutional Review Board approval.

RESULTS

Case Finding

We identified 8 cases of VIM-CRPA linked to hospitalization at ACH A from 2018 to 2020 (Figure 1). The earliest case (Case A) was identified during a CPO point prevalence screening at a local ventilator-capable skilled nursing facility that was performed as part of a separate outbreak investigation. The remainder of cases were diagnosed as follows: 1 from a clinical culture collected at a separate acute care hospital, ACH B (Case B); 3 from routine admission screenings performed at local LTACH A (Cases C, D, and G); and 3 from CPO screening of patients being discharged from ACH A ICU Room X (Cases E, F, and H).

Colonization screening of patients at discharge from ICU Room X occurred from January to November 2020; 4 cases (Cases E–H) were identified from January to June, and none were identified from July to November. From January to June (and before intensive facility interventions described below), 25 patients were admitted in Room X for a 5.2-day average duration of stay (range 0–15 days). Of these, 44% ($n = 11$) were screened at discharge. Among those screened during this timeframe, 3 cases were identified. Due to a missed discharge screen, an additional case was identified on admission to LTACH A after a direct transfer from Room X. The average length of stay in Room X for the 4 cases identified via discharge screening (Cases E–H) was 11.3 days (range 6–15 days), whereas the average length of stay for patients who tested negative was 5.4 days (range 2–11 days).

Reasons for missed discharge screens included patient expiration ($n = 5$), accidental omission by HCP at time of discharge ($n = 5$), and patient refusal ($n = 4$). The ACH A flagged the charts of these patients so that they would be placed on Contact Precautions and undergo CPO screening if readmitted to ACH A. Of the 14 with missed screens, the average length of stay was 3.3 days (range 0–8 days); 3 were discharged home, and 6 were discharged to postacute care facilities, including rehabilitation, behavioral health, psychiatric, and skilled nursing facilities. Patients were not screened on admission at these postacute care facilities; however, ACH A communicated with receiving facilities so that appropriate infection prevention measures could be taken. As of publication date and to our current knowledge based on a review of collected epidemiological data from reported statewide surveillance data of VIM cases, none of these patients with missed screens were readmitted to ACH A or tested positive for VIM-CRPA by screening or clinical testing at other facilities.

Infection Prevention and Control Assessments and Facility Interventions

The ICU of ACH A consisted of 18 private rooms, each with an individual handwashing sink within the room and a private bathroom with a sink, toilet, and shower for bathing. Handwashing sinks were also present in the ICU hallways in between patient rooms. Public health infection prevention and control (IPC) assessments performed in August 2019 and February 2020 identified the following concerns: sink faucets within patient rooms were noted to discharge directly above drains, disposal of intravenous (IV) fluids and medications in handwashing sinks, storage of medical equipment around the sinks, and regular use of soap and water (as opposed to alcohol-based hand sanitizer) for hand hygiene. In Room X specifically, sink drainage was sluggish and resulted in pooling within the basin. In response to these findings, recommendations were made to address sink drainage issues and to provide ongoing education on appropriate disposal of IV fluids and other liquids, instructions to avoid sink use inside the patient room to perform hand hygiene pending remediation of other issues, and the preferential use of alcohol-based hand sanitizer for general hand hygiene.

Despite the above recommendations, 3 additional cases (Cases F–H) were identified between March and June of 2020 (Figure 1). Therefore, the TDH performed a third site visit in June 2020, during which HCP reported that increased numbers of ICU patient admissions due to the coronavirus disease 2019 (COVID-19) pandemic had resulted in significant challenges in staffing, performing IPC audits, and compliance with CPO discharge screening of patients in Room X. However, the HCPs did report receiving refresher education on sink and water practices, and signs were posted at the nurse's work area outside of Room X to remind HCP to collect a discharge surveillance specimen and to adhere to Contact Precautions for all patients staying in this room.

The ACH A decided to temporarily close Room X to replace handwashing and bathroom sink basins and external plumbing hardware in Room X over the course of 4 days in early July 2020. In consultation with TDH and the CDC, daily 5-minute thermal water flushes (temperatures maintained at 112–114°C) followed by a cold-water flush were implemented for the handwashing sink, bathroom sink, and shower in Room X. Each faucet aerator in Room X was also cleaned with Virex (Diversey, Fort Mill, South Carolina, USA) every 15 days. After implementation of these facility interventions, 11 patients were admitted from July 2020 to November 2020 with an average duration of stay of 11.1 days (range 2–28 days). All 11 discharge screens were negative. Because no additional cases were identified, ACH A discontinued universal Contact Precautions from Room X in November 2020 and discontinued thermal flushes in November 2021.

Within the 18-month follow-up period after the last case, prospective surveillance continued; the ACH A continued to

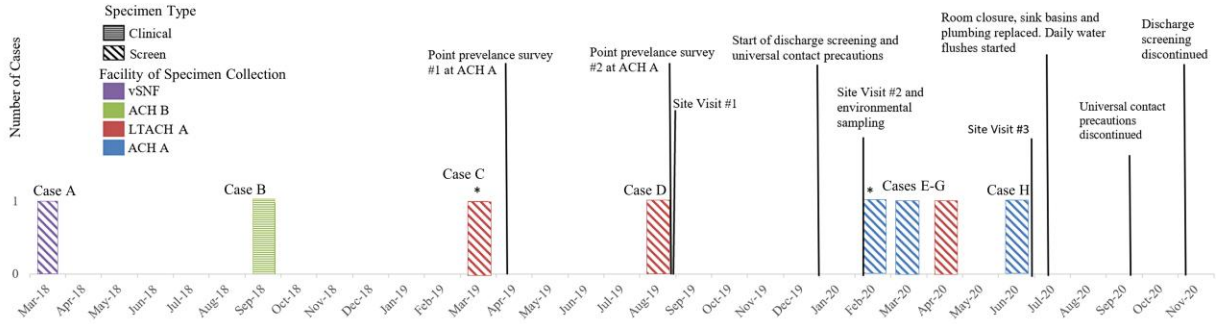

Figure 1. Verona integron-encoded metallo-beta-lactamase cases by month of specimen collection, location of collection, and timeline of interventions from March 2018 to November 2020 ($N = 8$). *No organism was viable for culture. ACH, acute care hospital; LTACH, long-term acute care hospital; vSNF, ventilator-capable skilled nursing facility.

Table 1. Pairwise SNV Distance Matrix of 5 Cases and 2 Environmental *Pseudomonas aeruginosa* Isolates With bla_{VIM-1}

Source	Case A	Case B	Case D	Case F	Case G	Room X_HWSD	Room X_BSD
Case A	…	6	0	3	4	8	9
Case B	6	…	6	9	10	4	5
Case D	0	6	…	3	4	8	9
Case F	3	9	3	…	7	11	12
Case G	4	10	4	7	…	13	13
Room X_HWSD	8	4	8	11	13	…	7
Room X_BSD	9	5	9	12	13	7	…

Abbreviations: bla_{VIM}, Verona-integron encoded metallo-β-lactamase; BSD, bathroom sink drain; HWSD, hand washing sink drain; SNV, single-nucleotide variant.

Two isolates with bla_{VIM} from cases (Case E and Case C) were unavailable for analysis due to a nonviable culture after detection. One Verona integron-encoded metallo-beta-lactamase-producing carbapenem-resistant *P. aeruginosa* isolate from a case (Case H) was detected after whole-genome sequencing analysis started and therefore was not included in this table and analysis.

monitor for clinical CRPA cases, and the TDH collected data regarding patient admissions for all reported VIM cases in the state, which allowed public health personnel to monitor for additional clinical VIM cases that may have been linked to Room X. The ACH A also completed a facility-wide retrospective laboratory review of clinical carbapenem-resistant organisms identified from November 2020 to April 2022; no CRPA isolates were identified, although no additional PPS were conducted after August 2019.

Environmental Testing and Whole-Genome Sequencing

Drain swabs from the handwashing and bathroom sinks in Room X, the handwashing sinks in Room Y, and an ICU hallway sink all grew *P. aeruginosa*. bla_{VIM} was detected in the isolates from both the bathroom and handwashing sinks in Room X, whereas no carbapenemase genes were detected in isolates from the handwashing sink drain in Room Y or from the ICU hallway sink. *P. aeruginosa* was not isolated from any water or sink aerator swabs collected. Whole-genome sequencing of *CRPA* isolates from 5 patients, the handwashing sink drain in Room X, and the bathroom sink drain in Room X were ST253 harboring the bla_{VIM-1} gene, whereas the noncarbapenemase-producing *P. aeruginosa* isolates from Room Y and the ICU hallway sink were ST235 and ST315, respectively. ST253 isolates were considered highly related, varying by 0–13 single-nucleotide variants (Table 1). Sequences are available at the National Center for Biotechnology Information (BioProject ID PRJNA288601).

DISCUSSION

This investigation identified transmission of VIM-CRPA from hospital sink drains to patients within a single ICU room over at least a 2-year period. A total of 8 cases were identified through a combination of point prevalence screening, discharge CPO screening at ACH A, and admission CPO screening at local LTACH A. This investigation confirms that outbreaks of MDROs linked to environmental reservoirs may be difficult to detect, and that persistent transmission can occur for months to years. Because the source of this outbreak may not have been discovered without colonization screenings at local postacute care settings, it also highlights the need for coordination of outbreak investigations between public health and multiple healthcare facilities across a region.

Our findings are consistent with prior outbreak reports linked to premise plumbing in healthcare facilities [3–6, 8, 9,

15]. A review of 32 outbreaks involving the hospital water environment identified contaminated sinks, drains, and faucets as the most common environmental reservoirs for carbapenem-resistant organisms; *P. aeruginosa* was the most frequently implicated organism in these outbreaks [7]. Similar outbreaks from environmental water reservoirs have been shown to have a mean outbreak duration of 37 months, and a faucet reservoir illustrated an outbreak that spanned 29 months, which is similar with our outbreak timeframe of at least 2 years [15, 16]. Our cases' average duration of stay was 11.3 days in Room X, which surpassed the average for those patients that tested negative. Longer length of stays have shown to be a risk factor of colonization/infection in similar environmental outbreaks [7].

Controlling outbreaks linked to plumbing has proven difficult, and multiple ongoing interventions are often necessary. Studies have demonstrated that complete removal of sinks and transition to a "waterless" patient care environment to be effective at reducing MDRO rates, although this is often not possible in most facilities [17, 18]. Prior outbreaks have shown that thermal flushes, chemical disinfectants, and/or sink and drain replacements are likely to only result in temporary elimination of biofilms. However, using such measures in combination with intensive IPC practices has been shown to successfully stop outbreaks [5, 7, 19]. In 2020, the US Environmental Protection Agency approved the first product labeled for disinfection of drain biofilms in healthcare settings. This product is an interesting development for use in healthcare settings; however, it is important to note that this product must be applied every 3–5 days to prevent biofilm recurrence [20].

Our onsite visits showed slow drainage in both Room X sinks, which likely contributed to dispersal of water contaminated with VIM-CRPA to surrounding areas. A combination of slow drainage speed and the positioning of the drain and faucet has been shown to increase dispersal from the drain's p-trap, which can lead to contamination by spreading MDROs to sink counters and surrounding sink areas [21]. Therefore, daily sink basin cleaning and sink hygiene audits were incorporated into ACH A's daily infection prevention rounds to try to prevent contamination of surrounding sink areas. The new handwashing and bathroom sinks in Room X included deeper sink basins with offset faucets, which have been shown to reduce splashes and microbial dispersion from the sink [5, 7, 22].

Due to the complexities of eliminating biofilms from environmental reservoirs, our recommendations focused heavily on improving IPC through onsite assessments. The hospital implemented intensive HCP training and daily rounds to ensure (1) no patient care items were stored within sink splash zones and (2) that liquids were discarded appropriately and not in patient sinks. Empiric use of Contact Precautions for patients admitted to Room X may also have prevented transmission beyond Room X. Although this outbreak was ultimately linked to sink drains at an acute care hospital, this outbreak likely would have gone undetected without proactive CPO screening and public health notification by postacute care settings. Five of eight cases were identified at facilities other than ACH A, which demonstrated an opportunity for introduction of VIM-CRPA in these other facilities, although notably no transmission at these facilities was identified based on the absence of clinical CRPA cases. There is no requirement in TN for postacute care facilities to routinely perform admission screening; LTACH A decided to perform routine screening on all new admissions for proactive surveillance. The continued use of laboratory surveillance in higher acuity long-term care settings will allow for rapid identification of targeted MDRO infections so that appropriate IPC risk assessments may be performed. In addition to appropriate interfacility communication upon patient transfers about MDRO status and risk, other methods to limit the spread of such organisms in high-acuity postacute care settings include admission screening and appropriate use of Contact Precautions [23]. Surveillance coordinated by public health can identify intervention points and, in this case, was able to identify a point source and stop transmission.

This investigation was subject to several limitations. A large portion of the investigation for this outbreak took place immediately before and throughout 2020 during the global COVID-19 pandemic. Although ACH A complied with initial IPC recommendations, patient surges and HCP turnover/shortages resulted in a lack of consistent adherence to recommended sink practices. Several patients were also transferred from ICU Room X before discharge screening could occur, which may have resulted in undetected cases. Although it is possible that contamination existed in multiple plumbing sites within the facility, we were reassured that the outbreak strain of CRPA was not identified in other parts of the ICU, nor were cases with VIM-CRPA identified in other units. We only collected rectal swabs for screening tests and recognize that patients may be colonized or infected at other sites during these types of outbreaks, which could lead to an underrepresentation of cases [6, 8]. In addition, limited data prevented us from understanding the patient-level risk factors for cases compared to noncases. The case-attack rate was high and positive patients had longer length of stays, although we did not have access to data to compare other clinical characteristics that may have predisposed patients to colonization.

CONCLUSIONS

In this study, we describe an outbreak of VIM-CRPA affecting at least 8 cases during 2018–2020 that was linked to plumbing in a healthcare facility. In our investigation, we found a combination of interventions including replacement of sinks and plumbing with models that improved drainage and reduced

splash potential from drains, water flushes, and heightened infection prevention awareness with daily sink disinfection to be effective for outbreak cessation with a follow-up period of 18 months after the last confirmed case. Interfacility communication upon patient transfers and admission screening in postacute care facilities are important tools to contain and detect outbreaks; responses must also be flexible and consider including active surveillance measures such as discharge colonization screening.

Supplementary Data

Supplementary materials are available at *Open Forum 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.

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References

1. Centers for Disease Control and Prevention. CDC's Antibiotic Resistance Threats in the United States, 2019. Available at: https://www.cdc.gov/drugresistance/biggest-threats.html. Accessed December 12, 2022.
2. Centers for Disease Control and Prevention. Reduce Risk from Water. Available at: https://www.cdc.gov/hai/prevent/environment/water.html. Accessed December 23, 2022.
3. Amoureux L, Riedweg K, Péchinot A, et al. Nosocomial infections with IMP-19–producing. Emerg Infect Dis **2017**; 23:304–7.
4. Decraene V, Phan HTT, George R, et al. A large, refractory nosocomial outbreak of Klebsiella pneumoniae carbapenemase-producing *Escherichia coli* demonstrates carbapenemase gene outbreaks involving sink sites require novel approaches to infection control. Antimicrob Agents Chemother **2018**; 62: e01689–18.
5. Parkes LO, Hota SS. Sink-related outbreaks and mitigation strategies in healthcare facilities. Curr Infect Dis Rep **2018**; 20:42.
6. Breathnach AS, Cubbon MD, Karunaharan RN, Pope CF, Planche TD. Multidrug-resistant *Pseudomonas aeruginosa* outbreaks in two hospitals: association with contaminated hospital waste-water systems. J Hosp Infect **2012**; 82:19–24.
7. Gordon AE K, Mathers AJ, Cheong EYL, et al. The hospital water environment as a reservoir for carbapenem-resistant organisms causing hospital-acquired infections—a systematic review of the literature. Clin Infecti Dis **2017**; 64:1436–44.
8. Salm F, Deja M, Gastmeier P, et al. Prolonged outbreak of clonal MDR *Pseudomonas aeruginosa* on an intensive care unit: contaminated sinks and contamination of ultra-filtrate bags as possible route of transmission? Antimicrob Resist Infect Control **2016**; 5:53.
9. Chapuis A, Amoureux L, Bador J, et al. Outbreak of extended-spectrum beta-lactamase producing *Enterobacter cloacae* with high MICs of quaternary ammonium compounds in a hematology ward associated with contaminated sinks. Front Microbiol **2016**; 7:1070.
10. Clegg WJ, Pacilli M, Kemble SK, et al. Notes from the field: large cluster of Verona integron-encoded metallo-Beta-lactamase–producing carbapenem-resistant *Pseudomonas aeruginosa* isolates colonizing residents at a skilled nursing facility—Chicago, Illinois, November 2016–March 2018. MMWR Morb Mortal Wkly Rep **2018**; 67:1130–31.
11. Ray MJ, Lin MY, Weinstein RA, Trick WE. Spread of carbapenem-resistant enterobacteriaceae among Illinois healthcare facilities: the role of patient sharing. Clin Infect Dis **2016**; 63:889–93.
12. Diene SM, Rolain JM. Carbapenemase genes and genetic platforms in Gram-negative bacilli: enterobacteriaceae, *Pseudomonas* and *Acinetobacter species*. Clin Microbiol Infect **2014**; 20:831–8.
13. Chai J, Donnelly T, Wong T, Bryce E. Environmental sampling of hospital surfaces: assessing methodological quality. Can J Infect Control **2018**; 33:138–45.
14. Pierce VM, Simner PJ, Lonsway DR, et al. Modified carbapenem inactivation method for phenotypic detection of carbapenemase production among enterobacteriaceae. J Clin Microbiol **2017**; 55:2321–33.
15. Prestel C, Moulton-Meissner H, Gable P, et al. Dialysis water supply faucet as reservoir for carbapenemase-producing *Pseudomonas aeruginosa*. Emerg Infect Dis **2022**; 28:2069–73.
16. Carling PC. Wastewater drains: epidemiology and interventions in 23 carbapenem-resistant organism outbreaks. Infect Control Hosp Epidemiol **2018**; 39:972–9.
17. Catho G, Martischang R, Boroli F, et al. Outbreak of *Pseudomonas aeruginosa* producing VIM carbapenemase in an intensive care unit and its termination by implementation of waterless patient care. Crit Care **2021**; 25:301.
18. Hopman J, Bos R, Voss A, et al. Reduced rate of MDROs after introducing 'water-free patient care' on a large intensive care unit in the Netherlands. Antimicrob Resist Infect Control **2015**; 4(Suppl 1):O40.
19. Hopman J, Meijer C, Kenters N, et al. Risk assessment after a severe hospital-acquired infection associated with carbapenemase-producing Pseudomonas aeruginosa. JAMA Netw Open **2019**; 2:e187665.
20. United States Environmental Protection Agency. Virasept. **2020**. Available at: https://www3.epa.gov/pesticides/chem_search/ppls/001677-00226-20200205.pdf. Accessed December 12, 2022.
21. Aranega-Bou P, George RP, Verlander NQ, et al. Carbapenem-resistant Enterobacteriaceae dispersal from sinks is linked to drain position and drainage rates in a laboratory model system. J Hosp Infect **2019**; 102:63–9.
22. Gestrich SA, Jencson AL, Cadnum JL, Livingston SH, Wilson BM, Donskey CJ. A multicenter investigation to characterize the risk for pathogen transmission from healthcare facility sinks. Infect Control Hosp Epidemiol **2018**; 39:1467–9.
23. Centers for Disease Control and Prevention. Interim guidance for a public health response to contain novel or targeted multidrug-resistant organisms (MDROs). Available at: https://www.cdc.gov/hai/containment/guidelines.html. Accessed March 1, 2019.