

Original Article

Sink traps as the source of transmission of OXA-48–producing *Serratia marcescens* in an intensive care unit

Gili Regev-Yochay MD, MS^{1,2}, Gill Smollan MD³, Ilana Tal RN¹, Nani Pinas Zade RN¹, Yael Haviv MD⁴, Valery Nudelman RN⁴, Ohad Gal-Mor PhD^{2,5}, Hanaa Jaber BsC¹, Eyal Zimlichman MD⁶, Nati Keller MD^{3,7} and Galia Rahav MD^{2,8}

¹Infection Prevention and Control Unit, Sheba Medical Center, Tel-Hashomer, Israel, ²Sackler School of Medicine, Tel Aviv University, Tel Aviv, Israel,

³Microbiology Laboratory, Sheba Medical Center, Tel-Hashomer, Israel, ⁴Intensive Care Unit, Sheba Medical Center, Tel-Hashomer, Israel, ⁵Infectious Diseases

Research Laboratory, Sheba Medical Center, Tel-Hashomer, Israel, ⁶Management, Sheba Medical Center, Tel-Hashomer, Israel, ⁷Ariel University, Ariel, Israel, and

⁸Infectious Disease Unit, Sheba Medical Center, Tel-Hashomer, Israel

Abstract

Background: Carbapenemase-producing *Enterobacteriaceae* (CPE) outbreaks are mostly attributed to patient-to-patient transmission via healthcare workers.

Objective: We describe successful containment of a prolonged OXA-48–producing *S. marcescens* outbreak after recognizing the sink traps as the source of transmission.

Methods: The Sheba Medical Center intensive care unit (ICU), contains 16 single-bed, semi-closed rooms. Active CPE surveillance includes twice-weekly rectal screening of all patients. A case was defined as a patient detected with OXA-48 CPE >72 hours after admission. A root-cause analysis was used to investigate the outbreak. All samples were inoculated on chrom-agar CRE, and carbapenemase genes were detected using commercial molecular Xpert-Carba-R. Environmental and patient *S. marcescens* isolates were characterized using PFGE.

Results: From January 2016 to May 2017, 32 OXA-48 CPE cases were detected, and 81% of these were *S. marcescens*. A single clone was the cause of all but the first 2 cases. The common factor in all cases was the use of relatively large amounts of tap water. The outbreak clone was detected in 2 sink outlets and 16 sink traps. In addition to routine strict infection control measures, measures taken to contain the outbreak included (1) various sink decontamination efforts, which eliminated the bacteria from the sink drains only temporarily and (2) educational intervention that engaged the ICU team and led to high adherence to ‘sink-contamination prevention guidelines.’ No additional cases were detected for 12 months.

Conclusions: Despite persistence of the outbreak clones in the environmental reservoir for 1 year, the outbreak was rapidly and successfully contained. Addressing sink traps as hidden reservoirs played a major role in the intervention.

(Received 23 May 2018; accepted 20 July 2018)

A nationwide outbreak of carbapenem-resistant *Enterobacteriaceae* (CRE) emerged in Israel in 2006, with nosocomial spread of *Klebsiella pneumoniae* carbapenemase (KPC)-producing *K. pneumoniae*. A national intervention was implemented in all acute-care hospitals including active surveillance of high-risk patients and carrier isolation and cohorting. With these efforts, the outbreak was partially contained,¹ yet carbapenemase-producing *Enterobacteriaceae* (CPE) remain still widespread in most of the large medical centers in Israel. Moreover, new types of CPE have emerged, including NDM-1– and OXA-48–producing *Enterobacteriaceae*.

Author for correspondence: Gili Regev-Yochay, Infection Prevention and Control Unit, Sheba Medical Center, Ramat Gan, Israel. E-mail: gili.regev@sheba.health.gov.il

PREVIOUS PRESENTATION: These data were partially presented at the 28th European Society of Clinical Microbiology and Infectious Diseases Conference (ECCMID) on April XX, 2018, in Madrid, Spain

Cite this article: Regev-Yochay G, et al. (2018). Sink traps as the source of transmission of OXA-48–producing *Serratia marcescens* in an intensive care unit. *Infection Control & Hospital Epidemiology* 2018, 39, 1307–1315. doi: 10.1017/ice.2018.235

OXA-48 enzymes, of the class D carbapenemases, were initially identified in Turkey² in *K. pneumoniae* and have recently emerged as a predominant carbapenemase type in various *Enterobacteriaceae* in other countries.³ The first cases of OXA-48–producing CPE in Israel were described in patients coming from the Palestinian Authority^{4,5} and from Syrian wounded refugees treated in Israeli hospitals.⁶

Carbapenemase-producing *Enterobacteriaceae* can produce a broad spectrum of infections; they associated with high mortality and very limited therapeutic options. Particularly troubling are *Serratia* and *Proteus*, which are innately resistant to colistin, one of the last-resort therapeutic options. Patient-to-patient cross transmission is the main mechanism of spread of multidrug-resistant (MDR) *Enterobacteriaceae* nosocomial outbreaks. Colonized patients are considered the most important reservoir, and infection control breaks in hand hygiene via healthcare workers is considered the predominant transmission chain.⁷ Environmental reservoirs have not been frequently reported as the source for such outbreaks.

Herein, we describe a prolonged ICU *S. marcescens* outbreak, at an ICU of a large tertiary-care medical center, which was successfully contained by a combined intervention after recognizing the sink traps as the source of transmission.

Methods

Setting and CPE surveillance and isolation policy

The Sheba Medical Center (SMC) is a tertiary-care academic medical center in central Israel, affiliated with the Tel Aviv University; it has 1,600 beds for both acute-care and rehabilitation patients, with 96,800 annual admissions to the acute-care hospital. The general ICU consists of 16 active beds for medical and surgical patients, with ~470 admissions per year. The mean ICU hospitalization duration is 9.6 days. The patient-to-nurse ratio is 2:1. Each bed is in a semi-closed space separated by glass walls on 2 sides. The water supply and the wastewater removal system in the ICU consists of 22 sinks, including a sink in each patient unit at the entrance to the room, 4 additional sinks in the general space, and 2 sinks in the staff toilet and dressing rooms.

Active surveillance CPE screening of all ICU patients has been in place since 2007 and includes admission as well as twice-weekly rectal screening. All high-risk patients are placed in pre-emptive isolation pending admission surveillance culture results. Once a patient is detected as a CPE carrier, he is moved to a designated cohort space with dedicated nursing staff and equipment.

Case definition and patient data

A case was defined as an ICU hospitalized patient with OXA-48-producing Enterobacteriaceae isolated either from surveillance cultures or from clinical cultures obtained at the SMC since 2016. Data collected from the electronic medical files included date of admission, date of CPE acquisition, source of admission (home, nursing home, etc), admission diagnosis, comorbidities, length of stay (LOS) until and after CPE acquisition, type of clinical infection, and outcome.

Microbiological methods

Clinical isolates were identified following Clinical and Laboratory Standards Institute (CLSI) guidelines. Antibiotic susceptibility was determined using the disk diffusion method. Minimum inhibitory concentrations (MICs) of carbapenems were determined using the Etest (AB Biodisk). The MIC break points were defined according to CLSI guidelines. Surveillance rectal samples and environmental samples were obtained using Copan Amies sterile transport swabs (Copan Diagnostics, Murrieta, CA). The rectal swab samples were streaked onto Chromagar KPC plates (Hy Laboratories, Rehovot, Israel) and incubated overnight at 35°C in ambient air. Suspicious colonies were identified using matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS). Carbapenemase genes were identified by polymerase chain reaction (PCR) using the Xpert Carba-R cartridge (GeneXpert, Cepheid, Sunnyvale, CA).

Molecular characterization of the outbreak and environmental isolates was performed using pulsed-field gel electrophoresis (PFGE),⁸ where *Xba*I-digested *Serratia* DNA embedded in agarose plugs were subjected to PFGE analysis at 14°C using CHEF-DR III system (Bio-Rad, Hercules, CA).

Outbreak investigation

During October 2016, after 6 patients with OXA-48-producing *S. marcescens* were detected, enhanced control measures were undertaken, including increased hand hygiene observations as well as educational sessions. Thorough cleaning of all surfaces and medical devices with 1,000 PPM sodium hypochlorite and quaternary ammonium, accordingly, was carried out. The number of ICU patients was cut from 16 to 8. The outbreak was partially contained, but a few weeks later, during March 2017, new acquisitions of OXA-48-producing *S. marcescens* were again identified.

At this point, we took a new investigational approach by engaging the ICU team in the process. We conducted 2 workshops (8 hours each) for the whole ICU team, including physicians, nurses, cleaning team, pharmacist, and social worker. The workshop included discussion groups that investigated potential infection control breaks that could explain the outbreak using a root-cause analysis with the fishbone visual approach (<http://www.siliconfareast.com/ishikawa.htm>).

Environmental sampling

Initial environmental sampling included swabs from beds, ventilators, mattresses, care carts, high-touch surfaces (eg, monitor and computer keyboards), IVAC pumps, several solutions, faucets, and water samples. Following the root-cause analysis, the water environment was suspected to be the source of transmission, and further environmental sampling included water samples, faucets, water pipes, sink surfaces, sink outlets, sink traps, and drain systems.

Results

Since 2007, when routine screening for CRE began in our hospital, and until 2016, 294 ICU patients acquired CRE, of whom ~70% had *Klebsiella pneumoniae* and only a single case had *Serratia marcescens*. Routine determination of the carbapenemase-producing genes began in 2013. Nearly all CPE isolates carried the *bla*_{KPC} gene, and only 6 isolates carried *bla*_{OXA-48} gene, 5 of which were *K. pneumoniae* and 1 was *Citrobacter freundii*.

Outbreak description

From January 2016 until May 2017, 658 patients were hospitalized at the ICU, of whom 41 patients (6.4%) acquired CPE. Of these, 31 (76%) acquired OXA-48-producing Enterobacteriaceae and 27 (87%) of these were *S. marcescens*. Five patients with OXA-48-producing *S. marcescens* acquired an additional OXA-48-producing Enterobacteriaceae. One patient acquired *S. marcescens* that harbored both *bla*_{OXA-48} and *bla*_{KPC} genes. Three additional patients were infected with KPC-producing *S. marcescens*. Patient characterizations of these 34 patients are presented in Table 1. Of 34 cases, 30 were initially detected by routine rectal screening; 11 patients developed clinical infections; and 3 mortality cases were attributed to the infection. Altogether 12 patients died, for an in-hospital mortality rate of 35%. Figure 1 presents the temporal relationship between the outbreak cases, and Figure 2 presents all CPE acquisitions in the ICU during the outbreak year.

Table 1. Clinical Characteristics of Patients With OXA-48 Carbapenemase-Producing *Enterobacteriaceae* (CPE)

	Sex	Age	Comorbidities	LOS Before, d ^a	Site of Detection	Site of Infection, (d) ^b	Bacteria	PFGE Type	LOS After, d ^{c,d}	Outcome	Antibiotic Susceptibility ^d
1	F	59	Sepsis, Perforation of colon	7	RS	Lung and blood (7 d)	<i>E. coli</i> - OXA48		180	Death	Amikacin, tobramycin
2	M	61	Motor vehicle accident	7	RS		<i>S. marcescens</i> - OXA48	A	4	Alive	
3	F	51	Suicide attempt	26	RS		<i>C. freundii</i> - OXA48		1	Alive	
4	M	38	Cerebrovascular accident	20	RS	Lung (5 d)	<i>S. marcescens</i> - OXA48	B	32	Alive	Cotrimoxazole, ceftazidime, azidothymidine, amikacin
5	F	42	Lymphoma, head tumor, hydrocephalus	24	RS		<i>S. marcescens</i> - OXA48	C	31	Death	
6	M	64	Burns	24	RS	Blood (21d)	<i>S. marcescens</i> - KPC	C [™]	60	Alive	Cotrimoxazole, amikacin
7	M	45	Motor vehicle accident	21	RS		<i>S. marcescens</i> - OXA48	C	24	Alive	
8	M	42	Intracranial hemorrhage due to trauma	39	RS		<i>E. coli</i> - OXA48	NA	80	Alive	
9	F	74	COPD, SCAP severe	17	RS		<i>S. marcescens</i> - OXA48	...	111	Death	
10	f	34	Brain edema pregnancy	20	RS	Blood (17 d)	<i>S. marcescens</i> - OXA48	C [™]	22	Death	Azidothymidine, amikacin, cotrimoxazole
11	M	78	Craniotomy due to ethmoid sinus cancer	21	RS		<i>S. marcescens</i>	C	8	Death	
12	f	79	Bladder cancer, <i>E. faecalis</i> endocarditis, septic shock	17	RS		<i>S. marcescens</i> - KPC	F	5	Death	
13	M	55	Cirrhosis, encephalopathy, bleeding varices	22	RS	Blood (5 d)	<i>S. marcescens</i> - OXA48	C	8	Death	
14	M	26	Multiple trauma fall	14	RS		<i>S. marcescens</i> - OXA48	C'	7	Alive	
15	M	36	Multiple trauma	14	L B + RS	Blood (1 d)	<i>K. pneumoniae</i> - OXA48 <i>S. marcescens</i> - OXA48	NA ...	5	Alive	Cotrimoxazole, ceftazidime, gentamycin, amikacin, ciprofloxacin, azidothymidine
16	M	70	Necrotizing pancreatitis, sepsis OXA-48 <i>K. pneumoniae</i>	58	B	Blood	<i>S. marcescens</i> - OXA48	...	16	Death	Cotrimoxazole, tobramycin, amikacin, ciprofloxacin
17	M	50	Multiple trauma	17	RS		<i>Enterobacter</i> sp.- OXA48	NA	15	Alive	
18	F	39	Schizophrenia, multiple trauma	20	RS RS		<i>S. marcescens</i> - OXA48 <i>K. pneumoniae</i> - OXA48	- NA	55	Alive	
19	F	65	Metastatic breast cancer, septic shock	27	RS RS		<i>S. marcescens</i> - OXA48 <i>K. pneumoniae</i> - OXA48	C NA	0	Alive	
20	M	50	B-cell lymphoma, septic shock	27	RS		<i>S. marcescens</i> - OXA48	C	10	Death	

Table 1. (Continued)

Sex	Age	Comorbidities	LOS Before, d ^a	Site of Detection	Site of Infection, (d) ^b	Bacteria	PFGE Type	LOS After, d ^{c,d}	Outcome	Antibiotic Susceptibility ^d	
21	M	35	Lymphoma, ulcerative colitis, necrotic bowel s/p laparotomy	7	Bile	Blood (2 d) abscess (90 d)	<i>S. marcescens</i> -OXA48	C ^{na}	25	Alive	Cotrimoxazole, amikacin
22	F	52	Metastatic cancer	29	RS		<i>S. marcescens</i> -OXA48	...	36	Death	
23	M	72	Ruptured aortic aneurysm	40	RS		<i>S. marcescens</i> -OXA48	...	9	Alive	
24	F	37	Necrotizing fasciitis	9	RS		<i>S. marcescens</i> -OXA48	C	17	Alive	
25	F	40	<i>S. pyogenes</i> , toxic shock syndrome related to birth	23	RS		<i>S. marcescens</i> -OXA48	C	3	Alive	
26	M	72	Neck abscess	17	RS		<i>S. marcescens</i> -OXA48 <i>Enterobacter</i> -OXA48	C NA	45	Alive	
27	M	21	Motor vehicle accident, anoxic brain	3	RS	Blood (74 d)	<i>K. pneumoniae</i> -OXA48 + KPC	NA	> 365	Alive	Gentamycin
28	M	78	Lymphoma, myelodysplastic syndrome, colon cancer	14	RS		<i>S. marcescens</i> -OXA48	C	15	Death	
29	F	59	Urosepsis, metastatic breast cancer	12	RS		<i>S. marcescens</i> -OXA48	C	34	Alive	
30	M	50	Multiple trauma	16	RS		<i>S. marcescens</i> -KPC	...	4	Death	
31	M	63	Gastrointestinal bleeding, gastric cancer, anoxic brain	13	L Wound		<i>K. pneumoniae</i> -OXA48 + KPC <i>S. marcescens</i> -OXA48 + KPC	NA C	27	Alive	Amikacin, tigecycline, colistin, cotrimoxazole
32	M	42	Fall, multiple trauma	17	RS		<i>S. marcescens</i> -OXA48	...		Alive	
33	F	69	MS, septic shock due to renal abscess	14	RS		<i>S. marcescens</i> -OXA48	C	18	Alive	
34	M	21	Multiple trauma gunshot wounds	14	RS RS (7 d) RS (19 d)	Blood (90 d) & urine (150 d)	<i>S. marcescens</i> -OXA48 <i>K. pneumoniae</i> -OXA48 <i>C. koseri</i> -OXA48	C NA NA	9	Alive	Cotrimoxazole, gentamycin, amikacin, ceftazidime, azidothymidine, colistin, ciprofloxacin, ceftazidime

Note. LOS, length of stay; PFGE, pulsed-field gel electrophoresis; RS, rectal swab; COPD, chronic obstructive pulmonary disease NA, nonapplicable (not a *Serratia* isolate); SCAP, severe community acquired pneumonia; MS, multiple sclerosis.

^aLength of stay (days) from admission until CPE was initially detected.

^bNo. of days after initial CPE detection.

^cLength of stay (days) from CPE detection until hospital discharge.

^dAntibiotic susceptibility of clinical strains.

Results of the outbreak investigation

Our initial investigation, including environmental sampling and consultations with the Israeli national infection control unit, did not identify any potential source. The root-cause analysis investigation revealed that significant use of tap water was a common factor in all cases. For most ICU procedures in which water is needed, sterile bottled water is used and tap water is used only for cleaning patients suffering from diarrhea, or rarely when flushing gastric tubes. Sampling of the water environment revealed

OXA-48–producing *S. marcescens* in many sink traps and sink outlets (Table 2).

Typing *S. marcescens* isolates

Of the 30 *S. marcescens* patient isolates, 26 were available and were characterized by PFGE. Apart from the first 2 cases, all OXA-48–producing *S. marcescens* isolates belonged to a single clone (defined 'C'). Notably, 1 of the KPC-producing *S. marcescens*

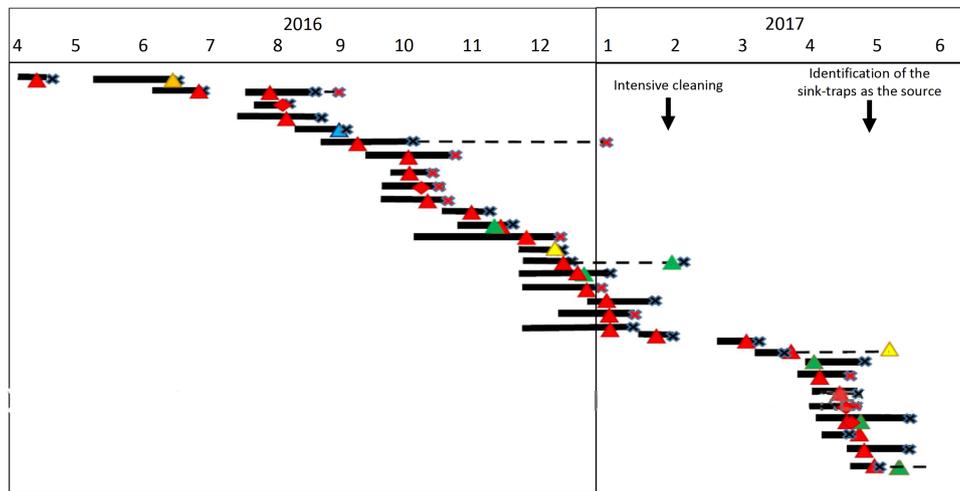


Fig. 1. Synoptic curve of patients colonized and/or infected with OXA-48-producing carbapenemase-producing *Enterobacteriaceae* (CPE) as well as *Klebsiella pneumoniae* carbapenemase (KPC)-producing *S. marcescens*. Black lines denote the duration of hospitalization in the intensive care unit ICU. Dashed lines denote hospitalization outside the ICU that had an unfavorable outcome (mortality or additional CPE acquisition). Note. X denotes the discharge day; red X denotes mortality; triangle denotes acquisition of OXA-48-producing carbapenemase; diamond denotes KPC-producing carbapenemase; red denotes *S. marcescens*; orange denotes *Citerobacter* sp.; blue denotes *E. coli*; yellow denotes *Enterobacter* sp; and green denotes *K. pneumoniae*.

as well as the KPC+OXA-48-producing isolate were non-distinguishable (clone 'C'). The other available KPC-producing *S. marcescens* isolate was distinct (defined 'F') (Table 1).

Of 101 *S. marcescens* isolates from the sinks, 57 were available for PFGE. All *S. marcescens* sink isolates belonged to 2 clones; 38 (67%) were nondistinguishable from the major outbreak clone ('C'). Most of these (55%) harbored both *bla*_{OXA48} and *bla*_{KPC} genes as detected by PCR, while in 29% only *bla*_{OXA48} was detected, in 11% only *bla*_{KPC} was detected, and in 2 isolates (5%) *bla*_{VIM} was detected together with *bla*_{OXA48} +/−*bla*_{KPC}. The second clone detected in the sinks was nondistinguishable from the KPC-producing *S. marcescens* of patient 12 (clone 'F'). Indeed, most of these isolates (63%) harbored only *bla*_{KPC}, but 7 isolates (37%), harbored *bla*_{OXA48} + *bla*_{KPC}.

Control and prevention measures

Following the identification of the sinks, and particularly the sink traps, as the source of transmission, we carried out 2 main measures: (1) sink-trap decontamination efforts and (2) an educational intervention enhancing specific infection control measures and focusing on the sink as a source of transmission. Within a few weeks, bed occupancy returned to full, with 15–16 patients consistently hospitalized in the ICU.

Sink-trap decontamination efforts

Following the identification of the sink traps as a source, all sink traps were replaced, and the water supply was treated according to the Prevention and Control of *Legionella* Infection Protocol (PCLIP). This intervention consisted of heating and hyperchlorination of the main water tank and terminal points for 12 hours with free residual chlorine (20–30 mg/L). Three days after this procedure, no CPE was detected in any sink trap. However, 10 days later, the outbreak clone was again detected in 14 of 16 sink traps (Figure 3).

Following Stjarne et al,⁹ sink traps were treated with 250 mL 25% acetic acid once weekly for 10 consecutive weeks. Sink traps were also sampled weekly before treatment. This treatment significantly reduced the number of contaminated sinks: 28% versus

85% in the intervention versus preintervention periods (Table 2, Figure 3). Notably, different sinks were contaminated each week, and the staff complained of the odor of acetic acid. On August 3, 2017, this intervention was discontinued. All sink traps were replaced again, and weekly sink-trap sampling continued.

Following Wolf et al,¹⁰ a single 'self-disinfecting' sink trap (Medizinische Hygiene-Siphone BIOREC MoveoMed, Dresden, Germany) was purchased (~US\$2,300 or ~2000 Euro) and installed in room 12, where a KPC-producing *K. pneumoniae* had been detected 1 week earlier (Figure 4). This sink trap presumably prevents the formation of a biofilm by means of permanent physical disinfection (heating and ultrasound), electromagnetic cleansing, and antibacterial coating. In the following weeks, the same bacteria continuously grew in the sink outlet despite the experimental sink trap. One month after installation of this sink trap, a patient in room 11 acquired a genetically similar KPC-producing *K. pneumoniae*. This sink trap was therefore replaced back to a standard sink trap. Currently, a strict daily cleaning protocol with 1,000 ppm hypochlorite is being used, and once-monthly sink-trap surveillance is carried out. The current average proportion of contaminated sinks is ~15% (Table 2).

Educational intervention

A bundled intervention to decrease CPE transmission has been implemented in our institution for a decade as described above. Hand hygiene compliance has been persistently ~80% in the pre-outbreak year. To further engage the ICU team, we conducted 2 workshops, as described above. Following the first workshop, we identified the sink traps as the source of transmission. The second workshop focused on measures to avoid further transmission from contaminated sinks. Strict guidelines on sink use were enforced: (1) using sinks only for hand washing and only when necessary, (2) prohibiting contamination of sinks with clinical waste disposal, and (3) prohibiting storage of materials around the sinks. Adherence to these measures was continuously encouraged by the infection control unit as well as by the ICU team itself, with update presentations, observations, and 10-minute 'time-out' sessions.

Table 2. Environmental Samples

Environmental Sources Sampled	Result	No. Positive Isolates
Preintervention period (Nov 2016–Apr 2017)		
<i>Ventilators</i>		
Expiratory valve, internal and external filters	Negative	
<i>Beds</i>		
Bed rails, mattresses	Negative	
<i>Ultrasound</i>		
Ultrasound probes, screen, handles, probe stations	Negative	
<i>Patient cooling device</i>		
External machine and water outlets	Negative	
<i>Additional equipment</i>		
Computer keyboard, isolation equipment stands	Negative	
<i>Dialysis equipment</i>		
Drainage system, water outlet	Negative	
<i>Sink environment</i>		
Tap water	Negative	
Faucets	Negative	
Faucet filters	Negative	
Sink outlets (n = 5)	<i>S. marcescens</i> - OXA48 + KPC	5
Sink traps (n = 20; 85% positive)	<i>S. marcescens</i> - OXA48 + KPC	14
	<i>S. marcescens</i> -OXA48	2
	<i>S. marcescens</i> - KPC	1
Central pipe trap (n = 1)	<i>S. marcescens</i> - OXA48	1
Intervention period 1: Acetic acid (May 2017–Aug 2017)		
Sink traps (n = 141; 26% positive)	<i>S. marcescens</i> - OXA48 + KPC	19
	<i>S. marcescens</i> - OXA48	6
	<i>S. marcescens</i> - OXA48 + VIM	2
	<i>S. marcescens</i> - OXA48 + VIM + KPC	1
	<i>S. marcescens</i> - KPC	1
	<i>Enterobacter</i> sp-KPC	4
	<i>Enterobacter</i> sp-KPC + VIM + NDM	1

Table 2. (Continued)

Environmental Sources Sampled	Result	No. Positive Isolates	
	<i>K. pneumoniae</i> -NDM	1	
	<i>Kluyvera accorbat</i> -KPC	2	
Intervention period 2: only strict sink cleaning (Aug 2017–Apr 2018)			
Sink traps (n = 289; 16% positive)	<i>S. marcescens</i> - OXA48 + KPC	16	
	<i>S. marcescens</i> - OXA48	10	
	<i>S. marcescens</i> - KPC	7	
	<i>S. marcescens</i> - OXA48 + VIM + KPC	2	
	<i>K. pneumoniae</i> - KPC	5	
	<i>Enterobacter</i> sp- KPC	6	
	Sink outlets (n = 311; 11% positive)	<i>S. marcescens</i> - OXA48 + KPC	7
		<i>S. marcescens</i> - OXA48	5
		<i>S. marcescens</i> - KPC	3
		<i>S. marcescens</i> - OXA48 + VIM + KPC	1
	<i>K. pneumoniae</i> - KPC	14	
	<i>K. pneumoniae</i> - NDM1	1	
	<i>Enterobacter</i> sp- KPC	4	

To further increase awareness and transparency, the number of days without CPE acquisition were posted daily on a centrally located infection control board. On day 100 without CPE acquisition, a celebration was organized with the medical center director, the infection control team, and the ICU teams.

Intervention outcome and follow-up

The last CPE *S. marcescens* detected in ICU patients, and in general in our medical center, occurred on May 7, 2017, 1 week after the identification of the sink traps as a source of transmission of CPE *S. marcescens*. Despite continuous growth of carbapenemase-producing *S. marcescens* in some of the sink traps in the ICU for >11 months, the transmission ceased. Since May 2017, a few CPE-infected patients have been hospitalized in the ICU, but the only 2 CPE acquisitions documented in the ICU were KPC-producing *K. pneumoniae*, which was probably transmitted from the sink in which the MoveoMed siphon was installed.

Discussion

We describe an OXA-48–producing *S. marcescens* outbreak in an ICU of a large tertiary-care medical center, and we have demonstrated that the source of transmission was the sink traps. We show that complete elimination of CPE from the sink traps was not successful despite various decontamination approaches,

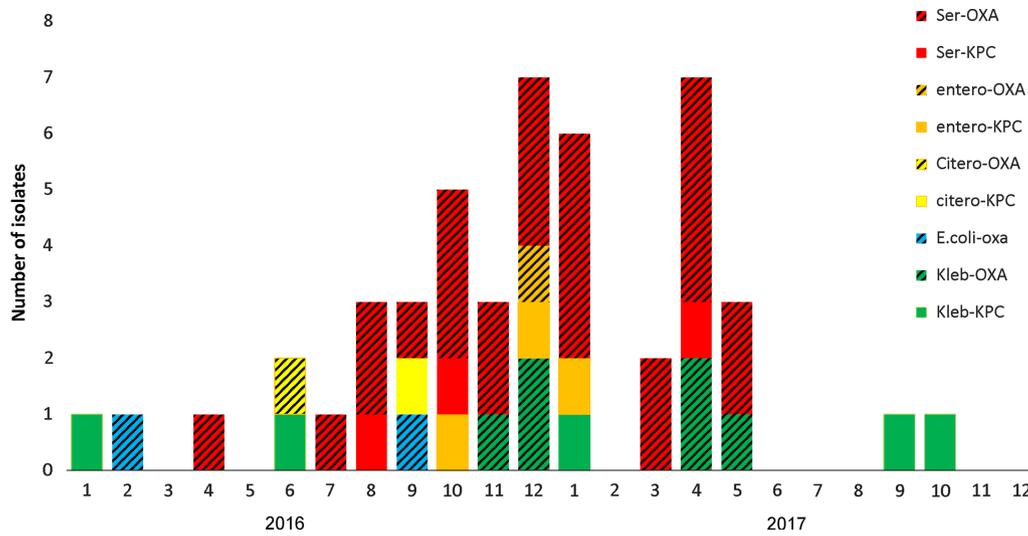


Fig. 2. Carbapenemase-producing *Enterobacteriaceae* (CPE) acquisitions in the intensive care unit (ICU) during 2016–2017.

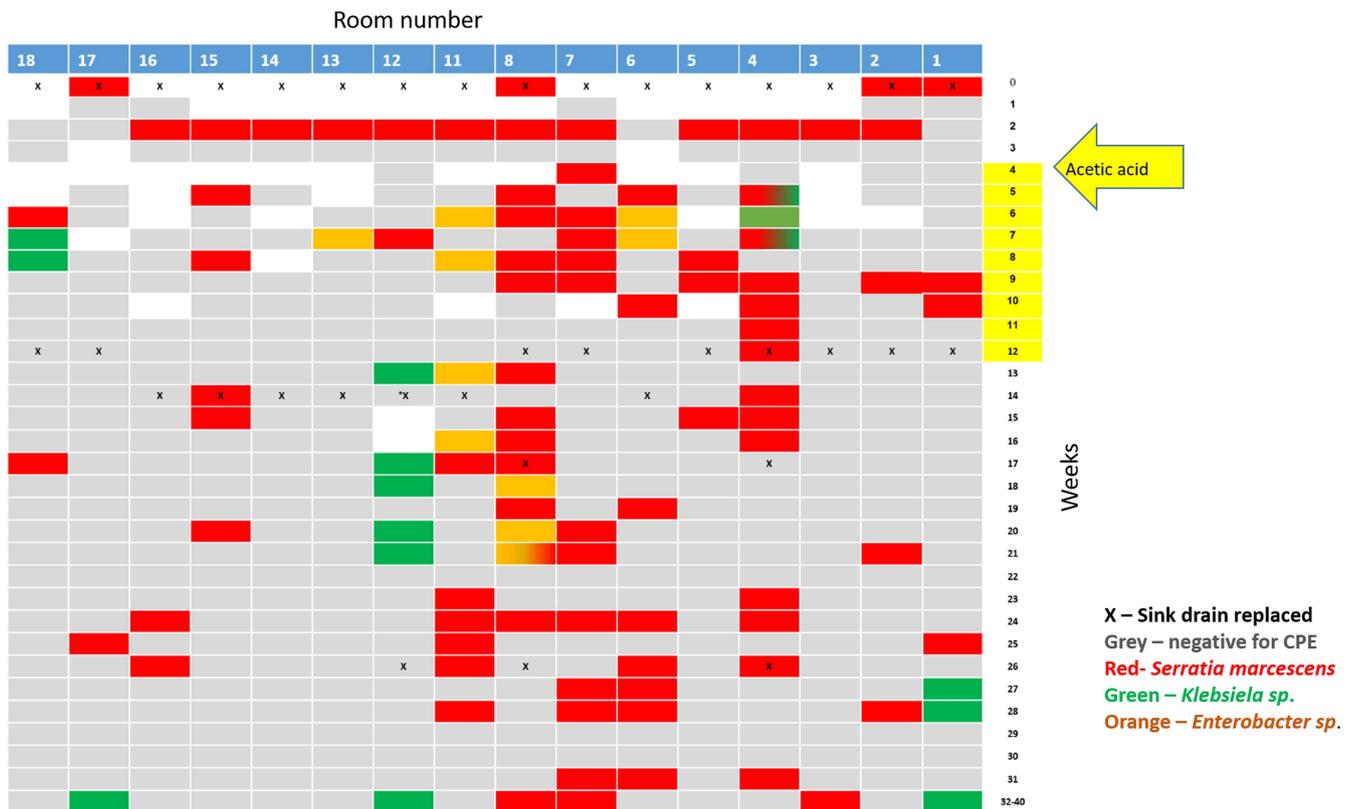


Fig. 3. Results of the weekly surveillance of sink traps in the ICU and the concurrent sink-trap interventions.

even after nearly 1 year without hospitalized colonized patients as well as several replacements of the sink traps. The outbreak, however, was rapidly contained by a combined intervention: conducting an educational intervention, engaging the team with focus on the proper use of sinks in the ICU, and reducing the environmental contamination load.

Environmental transmission has been considered to have a negligible role in CPE outbreaks and CPE transmission, while patient-to-patient transmission via the hands of healthcare workers has been considered the major route of transmission.⁷ However, the hospital water environment is increasingly

recognized as a potential source of carbapenem-resistant organism (CRO) transmission.^{11,12} Most reports on CRO outbreaks related to a water reservoir describe *Pseudomonas* spp or *Acinetobacter baumannii* outbreaks,^{9,12–14} with only a few CPE outbreaks directly related to water reservoirs, including a KPC-2 producing *K. oxytoca*,¹⁵ IMP-4-producing *Enterobacter cloacae*,¹⁶ KPC-2-producing *K. pneumoniae*,¹⁷ and recently, OXA-48-producing *C. freundii*.¹⁸

The *Serratia* species is known to survive and grow in moist environments. Several *Serratia* outbreaks have been associated with contaminated liquids including saline bottles,¹⁹ chlorhexidine,^{20–22}

and IV pain control fluids.²³ However, the sink environment as a potential source has been suggested only rarely. Ivady *et al*²⁴ reported 2 consecutive *S. marcescens* outbreaks in a NICU where the epidemic strain was detected in 1 culture of a tap water sample between the 2 outbreaks, despite many negative environmental cultures obtained during the outbreaks. Kotsanas *et al*²⁵ reported the persistence of *S. marcescens* in several sink traps of an ICU during a CPE outbreak of various species, where 4 of 11 clinical cases were due to IMP-4-producing *S. marcescens*.

Sink traps have been recently suggested to be a hidden source of gram-negative rod outbreaks in general and CRO in particular.^{10,18,25–27} The mechanism of transmission from sink traps to patients is probably that running water drives aerosol contaminated with bacteria from the biofilm of the sink trap to the sink surrounding. Using a fluorescent marker, it was demonstrated that drain contents splashed at least 1 meter from the sink during hand washing.^{28,29} Furthermore, we observed sterile materials and devices that were about to be inserted into the patients that were misplaced in the very near surrounding of the sinks in the ICU.

The source for the initial OXA-48-producing *S. marcescens* in our medical center is unclear. Despite rigorous screening for CPE, OXA-48-producing *S. marcescens* was never detected in our medical center during at least 6 years before the outbreak. A few cases of KPC-producing *S. marcescens* were previously identified in our ICU as well as a single case of OXA-48-producing *K. pneumoniae*. As intra- and interpatient dissemination of *bla*_{OXA-48} from one species to another has been previously reported.³⁰ Many of the carbapenemase-producing *S. marcescens* found in the sink traps in our ICU harbored both *bla*_{KPC} and *bla*_{OXA-48}, suggesting evolution of multiple CPE in the sink-trap microbiome. Flushing fluids containing antibiotics, including colistin, into the sinks could have further promoted selection of resistant bacteria, particularly *Serratia*, which are innately resistant to colistin.

The persistence of CPE, and particularly the epidemic strain, for many months after the last infected patient was discharged highlights the importance of this underappreciated environmental reservoir and suggests that the plumbing system is persistently contaminated, even after intensive decontamination efforts including PCIP treatment, weekly treatment with acetic acid, and repeated sink-trap replacement. Indeed, Weingarten *et al*³¹ showed that wastewater pipes are a vast resilient reservoir of CPOs; they found common plasmid backbones in both environmental areas and in the patient population. The various infection control strategies to contain outbreaks related to hospital water environment were recently summarized,¹² but none of the strategies reviewed (including bleach, hydrogen peroxide, UV light, or sink and drainage system replacement) was particularly successful, similar to our experience. Especially concerning was the failure of the new and expensive Moveosiphon technology in our experience. Our result is somewhat unlike that of Mathers *et al*,²⁷ who reported a successful bundled intervention including hopper covers and use of the Moveosiphon. However, they concluded that their ability to assess the efficacy of these self-disinfecting sink traps was limited and requires further evaluation.

While our sink-trap decontamination efforts were not completely successful, they did reduce the number of contaminated sinks and, thus, the overall level of environmental contamination. The second arm of our intervention was an intensive effort to educate the healthcare teams and to engage them in behavioral

changes required with regard to the underappreciated contamination risk of the sink surrounding.

It is difficult to measure the role of each of the intervention arms. However, we believe that the team compliance with the new strict sink-use guidelines played a major role in the containment. Engaging teams to a culture change in the field of infection control is extremely complicated, particularly in an ICU, where the treatment of severely acute patients is a high-pressure environment for healthcare workers.

Our study has several limitations. First, we used a 2-arm intervention, and it is impossible to determine the particular role of each arm. Second, the molecular characterization of the isolates was conducted using PFGE. Further analysis using whole-genome sequencing could further clarify the evolution of CPE in sink traps. Last, while we demonstrate the failure of the self-disinfecting sink trap (Moveo), we installed only a single device.

Currently, there seems to be no complete solution for preventing CRO transmission from sink traps to patients. Patient room architecture and sink designs should be carefully conceived. Eliminating sinks in ICU rooms has been suggested,³² but this would raise many difficulties because hand washing is frequently necessary, even in the era of alcohol-based hand hygiene, mainly when handling patients with *C. difficile* infections. A technical plumbing solution, a chemical solution, or an architectural solution should be sought. Meanwhile, healthcare teams should be educated to understand the important role of this hidden reservoir: the sink trap.

Acknowledgments. We thank the ICU team for their cooperation, especially Dr Nir Shimony and Dr David Livingstone for their deep involvement. We thank the Sheba logistic team, particularly the plumbers, Arie Hikrey and Avi Simchi, for their assistance. We thank the Infection Prevention and Control team for their dedicated work, and Aylana Reiss-Mandel for her assistance in the laboratory work, as well as Ronen Gellstein, Raya Bornstein, and Iris Stein from Magen Haim for their continuous support.

Financial support. No financial support was provided relevant to this article.

Conflicts of interest. All authors report no conflicts of interest relevant to this article.

References

- Schwaber MJ, Carmeli Y. An ongoing national intervention to contain the spread of carbapenem-resistant Enterobacteriaceae. *Clin Infect Dis* 2014;58:697–703.
- Poirel L, Heritier C, Tolun V, Nordmann P. Emergence of oxacillinase-mediated resistance to imipenem in *Klebsiella pneumoniae*. *Antimicrob Agent Chemother* 2004;48:15–22.
- Mataseje LF, Boyd DA, Fuller J, *et al*. Characterization of OXA-48-like carbapenemase producers in Canada, 2011–2014. *J Antimicrob Chemother* 2017. doi: 10.1093/jac/dkx462.
- Adler A, Solter E, Masarwa S, *et al*. Epidemiological and microbiological characteristics of an outbreak caused by OXA-48-producing Enterobacteriaceae in a neonatal intensive care unit in Jerusalem, Israel. *J Clin Microbiol* 2013; 51:2926–2930.
- Goren MG, Chmelnitsky I, Carmeli Y, Navon-Venezia S. Plasmid-encoded OXA-48 carbapenemase in *Escherichia coli* from Israel. *J Antimicrob Chemother* 2011; 66:672–673.
- Lerner A, Solter E, Rachi E, *et al*. Detection and characterization of carbapenemase-producing Enterobacteriaceae in wounded Syrian patients admitted to hospitals in northern Israel. *Eur J Clin Microbiol Infect Dis* 2016;35:149–154.

7. Friedman ND, Carmeli Y, Walton AL, Schwaber MJ. Carbapenem-resistant Enterobacteriaceae: a strategic roadmap for infection control. *Infect Control Hosp Epidemiol* 2017;38:580–594.
8. Ribot EM, Fair MA, Gautom R, et al. Standardization of pulsed-field gel electrophoresis protocols for the subtyping of *Escherichia coli* O157:H7, *Salmonella*, and *Shigella* for PulseNet. *Foodborne Pathogen Dis* 2006;3:59–67.
9. Stjerne Aspelund A, Sjostrom K, Olsson Liljequist B, Morgelin M, Melander E, Pahlman LI. Acetic acid as a decontamination method for sink drains in a nosocomial outbreak of metallo-beta-lactamase-producing *Pseudomonas aeruginosa*. *J Hosp Infect* 2016;94:13–20.
10. Wolf I, Bergervoet PW, Sebens FW, van den Oever HL, Savelkoul PH, van der Zwet WC. The sink as a correctable source of extended-spectrum beta-lactamase contamination for patients in the intensive care unit. *J Hosp Infect* 2014;87:126–130.
11. Kanamori H, Weber DJ, Rutala WA. Healthcare outbreaks associated with a water reservoir and infection prevention strategies. *Clin Infect Dis* 2016; 62:1423–1435.
12. Kizny Gordon AE, 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 Infect Dis* 2017;64:1435–1444.
13. Lalancette C, Charron D, Laferriere C, et al. Hospital drains as reservoirs of *Pseudomonas aeruginosa*: multiple-locus variable-number of tandem repeats analysis genotypes recovered from faucets, sink surfaces and patients. *Pathogens*. 2017;6(3). doi: 10.3390/pathogens6030036.
14. 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.
15. Leitner E, Zarfel G, Luxner J, et al. Contaminated handwashing sinks as the source of a clonal outbreak of KPC-2-producing *Klebsiella oxytoca* on a hematology ward. *Antimicrob Agent Chemother* 2015;59:714–716.
16. Betteridge T, Merlino J, Natoli J, Cheong EY, Gottlieb T, Stokes HW. Plasmids and bacterial strains mediating multidrug-resistant hospital-acquired infections are coreidents of the hospital environment. *Microb Drug Resist* 2013; 19:104–109.
17. Tofeland S, Naseer U, Lislevand JH, Sundsfjord A, Samuelsen O. A long-term low-frequency hospital outbreak of KPC-producing *Klebsiella pneumoniae* involving intergenus plasmid diffusion and a persisting environmental reservoir. *PLoS One* 2013;8:e59015.
18. De Geyter D, Blommaert L, Verbraeken N, et al. The sink as a potential source of transmission of carbapenemase-producing Enterobacteriaceae in the intensive care unit. *Antimicrob Resist Infect Control* 2017;6:24.
19. Us E, Kutlu HH, Tekeli A, Ocal D, Cirpan S, Memikoglu KO. Wound and soft-tissue infections of *Serratia marcescens* in patients receiving wound care: a healthcare-associated outbreak. *Am J Infect Control* 2017;45:443–447.
20. Morillo A, Torres MJ, Alonso Salas MT, Conde M, Aznar J. Implication of a national outbreak of *Serratia marcescens* associated with a contaminated solution of chlorhexidine in a paediatric hospital. *An Pediatr (Barc)* Mar 2018;88:171–172.
21. Merino JL, Bouarich H, Pita MJ, et al. *Serratia marcescens* bacteraemia outbreak in haemodialysis patients with tunnelled catheters due to colonisation of antiseptic solution. Experience at 4 hospitals. *Nefrologia* 2016;36:667–673.
22. de Frutos M, Lopez-Urrutia L, Dominguez-Gil M, et al. *Serratia marcescens* outbreak due to contaminated 2% aqueous chlorhexidine. *Enferm Infecc Microbiol Clin* 2017;35:624–629.
23. Chiang PC, Wu TL, Kuo AJ, et al. Outbreak of *Serratia marcescens* postsurgical bloodstream infection due to contaminated intravenous pain control fluids. *Int J Infect Dis* 2013;17:e718–e722.
24. Ivady B, Szabo D, Damjanova I, Pataki M, Szabo M, Kenesei E. Recurrent outbreaks of *Serratia marcescens* among neonates and infants at a pediatric department: an outbreak analysis. *Infection* 2014;42:891–898.
25. Kotsanas D, Wijesooriya WR, Korman TM, et al. “Down the drain”: carbapenem-resistant bacteria in intensive care unit patients and handwashing sinks. *Med J Austral* 2013;198:267–269.
26. Leung GH, Gray TJ, Cheong EY, Haertsch P, Gottlieb T. Persistence of related bla-IMP-4 metallo-beta-lactamase-producing Enterobacteriaceae from clinical and environmental specimens within a burns unit in Australia—a six-year retrospective study. *Antimicrob Resist Infect Control* 2013;2:35.
27. Mathers AJ, Vegesana K, German Mesner I, et al. Intensive care unit wastewater interventions to prevent transmission of multi-species *Klebsiella pneumoniae* carbapenemase (KPC) producing organisms. *Clin Infect Dis* 2018;67:171–178.
28. Hota S, Hirji Z, Stockton K, et al. Outbreak of multidrug-resistant *Pseudomonas aeruginosa* colonization and infection secondary to imperfect intensive care unit room design. *Infect Control Hosp Epidemiol* 2009; 30:25–33.
29. Kotay S, Chai W, Guilford W, Barry K, Mathers AJ. Spread from the sink to the patient: in situ study using green fluorescent protein (GFP)-expressing *Escherichia coli* to model bacterial dispersion from handwashing sink-trap reservoirs. *Appl Environ Microbiol* 2017;83(8):e03327–16.
30. Arana DM, Saez D, Garcia-Hierro P, et al. Concurrent interspecies and clonal dissemination of OXA-48 carbapenemase. *Clin Microbiol Infect* 2015;21:148:e141–e144.
31. Weingarten RA, Johnson RC, Conlan S, et al. Genomic analysis of hospital plumbing reveals diverse reservoir of bacterial plasmids conferring carbapenem resistance. *mBio* 2018;9:e02011–17.
32. Hopman J, Tostmann A, Wertheim H, et al. Reduced rate of intensive care unit acquired gram-negative bacilli after removal of sinks and introduction of ‘water-free’ patient care. *Antimicrob Resist Infect Control* 2017;6:59.