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Characterizations of handwashing sink activities in a single hospital medical intensive care unit

M. Grabowski [a], J.M. Lobo [a], B. Gunnell [b], K. Enfield [c], R. Carpenter [d], L. Barnes [e], A.J. Mathers [f,g,*]

[a] Department of Public Health Sciences, University of Virginia, School of Medicine, Charlottesville, VA, USA
[b] Center for Telehealth, University of Virginia Health System, Charlottesville, VA, USA
[c] Division of Pulmonary and Critical Care Medicine, Department of Medicine, University of Virginia Health System, Charlottesville, VA, USA
[d] University of Virginia School of Nursing, Charlottesville, VA, USA
[e] Department of Systems and Information Engineering, University of Virginia, Charlottesville, VA, USA
[f] Division of Infectious Disease and International Health, Department of Medicine, University of Virginia Health System, Charlottesville, VA, USA
[g] Clinical Microbiology Laboratory, Department of Pathology, University of Virginia Health System, Charlottesville, VA, USA

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S U M M A R Y

Background: Handwashing sink drains are increasingly implicated as a potential reservoir of antibiotic-resistant bacteria in hospital outbreaks; however, usage patterns that may promote this source remain unknown.
Aim: To understand behaviours in the intensive care unit (ICU) that may facilitate establishment and nosocomial transmission of multidrug-resistant Gram negatives from a sink-trap reservoir to a patient.
Methods: Motion-sensitive cameras captured anonymized activity paired with periodic in-person observations during a quality investigation from four ICU sinks (two patient rooms and two patient bathrooms) in a university hospital.
Findings: We analysed 4810 sink videos from 60 days in patient rooms (3625) and adjoining bathrooms (1185). There was a false-positive rate of 38% (1837 out of 4810) in which the camera triggered but no sink interaction occurred. Of the 2973 videos with analysed behaviours there were 5614 observed behaviours which were assessed as: 37.4% medical care, 29.2% additional behaviours, 17.0% hand hygiene, 7.2% patient nutrition, 5.0% environmental care, 4.2% non-medical care. Handwashing was only 4% (224 out of 5614) of total behaviours. Sub-analysis of 2748 of the later videos further categorized 56 activities where a variety of nutrients, which could promote microbial growth, were disposed of in the sink.
Conclusion: Several non-hand hygiene activities took place regularly in ICU handwashing sinks; these may provide a mechanism for nosocomial transmission and promotion of bacterial growth in the drain. Redesigning hospital workflow and sink usage may be

* Corresponding author. Address: P.O. Box 800255, Charlottesville, VA 22903, USA. Tel.: +1 434 982 4814; fax: +1 434 924 0075.
E-mail address: ajm5b@virginia.edu (A.J. Mathers).

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necessary as it becomes apparent that sink drains may be a reservoir for transmission of multidrug-resistant bacteria.

Introduction

The Centers for Disease Control and Prevention and the World Health Organization have both declared the development of antimicrobial resistance an urgent crisis for healthcare [1,2]. Gram-negative bacteria, especially those with carbapenem resistance, are thought to represent some of the most urgent pathogens with drug resistance because they leave vulnerable hospitalized patients with few treatment options [1]. There has been increasing awareness of sink traps or hospital wastewater plumbing acting as a reservoir for highly resistant Gram-negative bacteria in hospitals [3,4]. It is now recognized that Gram-negative bacteria can rapidly evolve and a sink drain could provide an ideal niche for exchange of drug resistance genes through horizontal exchange [5,6]. A knowledge gap remains in our understanding of how typical sink usage might promote seeding, establishment, or transmission of highly resistant organisms in a drain or sink trap.

Sink traps make ideal environmental reservoirs as they are often areas where complex bacterial biofilms can exist protected from removal by cleaning due to drain strainers or other physical barriers [7]. They can be seeded by drug-resistant bacteria which can then persist for several months [8,9]. Using a surrogate *Escherichia coli*, it was recently demonstrated that dispersion occurs from colonized drains into the sink bowl and surrounding environment [10]. However, this only occurred when nutrients were added to a sink laboratory system to promote growth. It has also been demonstrated that use of hospital sinks for activities other than handwashing is associated with higher rates of β-lactamase-producing Enterobacteriaceae [11]. Although much work is needed to understand how organisms move from a sink drain to a patient, there is limited knowledge on how hospital sinks are used outside of hand hygiene. Cataloguing frequency of nutrient exposure, use of sinks outside hand hygiene, additional substance disposal (e.g. antimicrobials), and cleaning frequency could assist in understanding factors which promote growth and dispersion in hospital sink drains. Other substances which cause further selection pressure, for example, antibiotic disposal or elimination of cleaning products such as quaternary ammonia, could also be important [12].

Our hospital has had ongoing transmission of multi-species carbapenemase-producing Enterobacteriaceae (CPE), which has not been well explained by patient-to-patient transmission [6,13]. More recently, in an attempt to eliminate transmission, we have recognized that CPE similar to those identified in our patients exist in the sink traps [14]. We undertook this quality investigation to assess whether there were human behaviours around sink usage which may be promoting carbapenemase-producing transmission in our medical ICUs (MICUs).

Due to the limited knowledge surrounding ICU sink usage, we sought to develop greater understanding of sink usage in hospital ICUs, outside of hand hygiene, to assess behaviours that might promote CPE growth and transmission. Documentation of sink usage through video surveillance, coupled with on-site observations, allows for improved hypothesis generation and identification of potential behaviours that could be eliminated to reduce sink-to-patient transmission.

Methods

Data source

Two MICU rooms (Figure 1a) in a 608-bed acute care hospital in central Virginia were set up for periodic observational video use between January and September 2016. Motion-sensitive D-Link DCS-2132L (two) and D-Link DCS-2230 (two) cameras (D-Link Systems Inc., Taipei, Taiwan), with day and night capabilities, were used for visual recording without sound. Videos were processed with Sighthound Video (Sighthound Inc., Menlo Park, CA, USA). Event footage was transmitted via an existing hospital Wi-Fi network and stored using Sighthound Video software (3.0.1 Pro) for later review. Objects entering the sink region triggered video storage and cameras were placed such that only the sink and immediate surroundings were in the field of view to maintain anonymity of room occupants and hospital staff (Figure 1b, c). We completed 24 h of in-person observation for rooms with cameras, in 4 h blocks, divided between rooms and shifts to validate camera functionality and to collect preliminary data on directionality of items interacting with the sink.

Both rooms had the same patient mix with a high level of acuity and a majority of patients immobile due to critical illness which could require ventilator, continuous renal replacement, and vasopressors. There was a sofa/bed in each room for companions to stay with patients. Patients seldom used the bathroom personally. Staff was informed at staff meetings of the video project as part of a quality investigation to understand potential routes of CPE transmission from sinks to patients and to develop interventions. As a quality investigation, Institutional Review Board approval was waived. Observations were maintained on a secure server and camera placement attempted to keep individuals anonymized by not capturing faces.

In an effort to capture all events, >24 h of continuous data were required for each camera day analysed, and days with incomplete data were eliminated (most often because of poor Wi-Fi connection). Singular quality camera days were eliminated if surrounded by days without quality camera function. Days used were selected by evaluating the length of gaps between videos and checking for changes in background features (items present), when time between recordings was >2 h, to assess whether unrecorded activity had occurred. Time-stamps in video feeds were used to correctly annotate videos when overlapping or duplications occurred in recording. Videos recorded with no active behaviour, due to triggering from individuals walking nearby or lighting changes (false positives), were also removed from analysis.

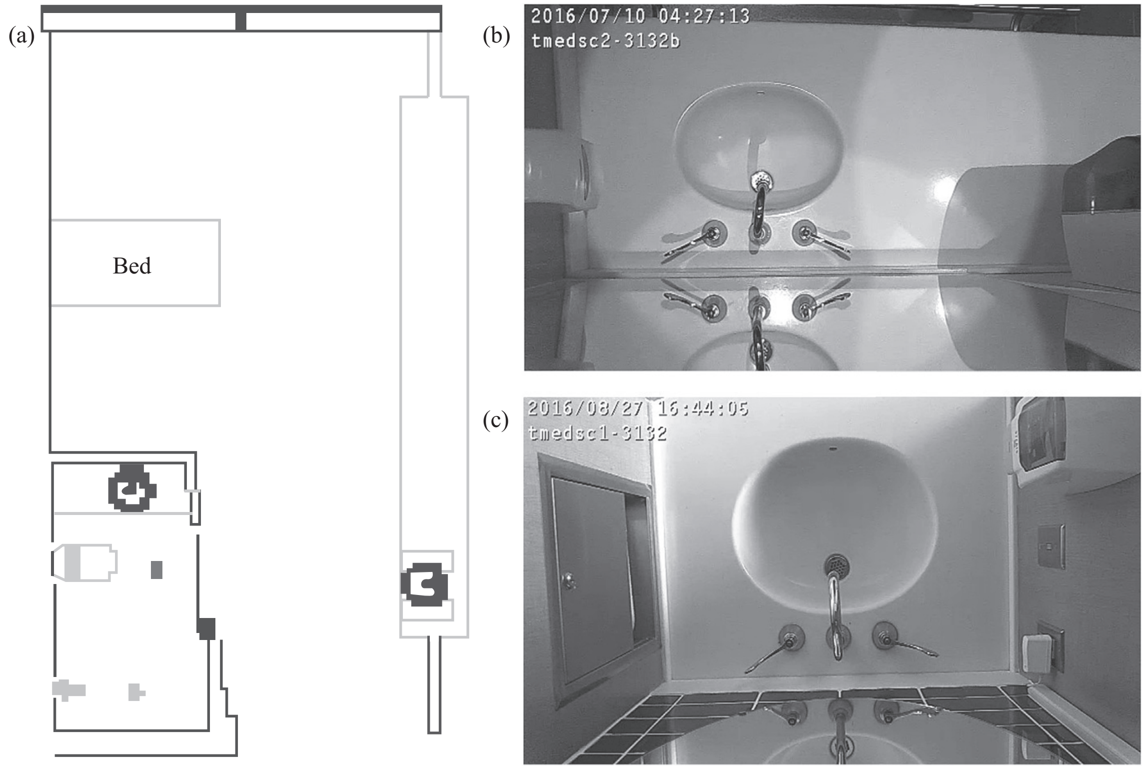

Figure 1. (a) Layout of the intensive care unit rooms and adjoining bathroom used in analysis; sinks in dark grey. (b) Camera image of patient room sink. (c) Camera image of patient bathroom sink.

Video categorization

To annotate the videos and the paired in-person observation, the Observer XT 12 (Noldus Information Technology, Inc., Leesburg, VA, USA) event recording software was used for manually reviewing and outputting frequency counts of each behaviour. The location of each camera (patient room and bathroom) was also recorded. A-priori knowledge of behaviours that may promote transmission from sink area to patient or biofilm growth in the trap as well as a preliminary analysis of pilot videos were used to develop a coding scheme for video analysis. The main categories were medical patient care, non-medical patient care, patient nutrition, hand hygiene, environmental care, and additional behaviours. A description of each category is included in Supplementary Table I. Direct comparisons between bathroom and patient room are presented by category (e.g. environmental care) rather than by individual behaviour. Items present were also documented by the sink at the start of a video and the percentage of time during which an item was present at the sink prior to use was calculated.

After initial review of the video data showed nutrient disposal, which could be critical to the issue of bacterial growth promotion, an attempt was made to increase resolution of the items being disposed of in the sink using additional behaviour modifiers that were tracked in the software. Categories of beverages emptied and size and fullness of IV bags were documented during this portion of the analysis. Non-water beverages were categorized as milk/supplemental nutrition drink, tea/coffee, and soft drink/juice based on liquid colour, opacity, beverage container, and behaviour similarities across videos. If we were unsure whether the beverage was non-water due to black and white videos (night vision) or lack of visibility, it was categorized as water so as not to overstate the amount of nutrient disposal. IV bags were categorized by size (small ~100 cc, medium ~1 L, or large ~5 L) and fullness (full/almost full, half full, or almost empty).

Results

Data used were from videos recorded for 30 complete days between April 25th, 2016 and May 22nd, 2016, and for 30 additional days between August 9th, 2016 and August 28th, 2016, with additional resolution on nutrient disposal. After elimination of videos with poor quality or inconsistent network connectivity, 29 days were analysed from room 1, 31 from room 2, 35 from bathroom 1, and 25 from bathroom 2. The most consecutive days analysed was 20 and least was one, with a mean of 12.

Of the 4810 videos recorded from the 60 patient room-days and 60 bathroom-days, 2973 videos contained a documentable event (false-positive rate of 38.2%, 1837 out of 4810 videos where the camera triggered but no sink interaction occurred). In the 2973 videos with sink-related behaviours, there were 4457 total actions, 74.3 actions per day, at the patient room sink, whereas the patient bathroom had only 1157 total actions with an average of 19.3 actions per day. The breakdown of actions is shown in Tables I and II. Medical patient care and additional behaviours were most frequent followed by activities related to hand hygiene for both sink locations. However, handwashing represented only 4% (224 out of 5614) of all observed actions. Note that it was possible for multiple actions to be observed in a single video.

Table I
Action counts and percentages for behaviours occurring at patient room sinks

Group	Action name	Action count	Count per room per day	Percent group	Percent total
Medical patient care	Fill syringe or medication cup[a,b]	590	9.83	32.92	13.24
	Empty syringe or medication cup[b]	337	5.62	18.81	7.56
	Drain IV bag[b]	112	1.87	6.25	2.51
	Medical item cleaned	53	0.88	2.96	1.19
	Medical item placed	297	4.95	16.57	6.66
	Medical item removed	331	5.52	18.47	7.43
	Medical packaging placed	24	0.40	1.34	0.54
	Medical packaging removed	16	0.27	0.89	0.36
	Non-categorized medical liquid emptied	21	0.35	1.17	0.47
	Non-categorized medical behaviour	11	0.18	0.61	0.25
	Total	1792	29.87	100	40.21
Non-medical patient care	Patient care item placed	41	0.68	19.81	0.92
	Patient care item removed	40	0.67	19.32	0.90
	Wetted/wrung patient rag[a,b]	126	2.10	60.87	2.83
	Total	207	3.45	100	4.64
Patient nutrition	Food/beverage placed	68	1.13	19.94	1.53
	Food/beverage removed	61	1.02	17.89	1.37
	Non-water beverage emptied	46	0.77	13.49	1.03
	Tube feed bag filled	23	0.38	6.74	0.52
	Tube feed bag emptied	4	0.07	1.17	0.09
	Water glass filled[a]	37	0.62	10.85	0.83
	Water glass emptied[b]	102	1.70	29.91	2.29
	Total	341	5.68	100	7.65
Hand hygiene	Soap use	194	3.23	23.29	4.35
	Paper towel	444	7.40	53.30	9.96
	Handwash	195	3.25	23.41	4.38
	Total	833	13.88	100	18.69
Environmental care	EVS staff wiped sink	40	0.67	23.39	0.90
	Non-EVS wiped sink	24	0.40	14.04	0.54
	Cleaning supplies placed	43	0.72	25.15	0.96
	Cleaning supplies removed	48	0.80	28.07	1.08
	Wetted/wrung cleaning rag	16	0.27	9.36	0.36
	Total	171	2.85	100	3.84
Additional behaviours	Personal item placed	78	1.30	7.01	1.75
	Personal item removed	78	1.30	7.01	1.75
	Non-categorized item placed	60	1.00	5.39	1.35
	Non-categorized item removed	63	1.05	5.66	1.41
	Water run	313	5.22	28.12	7.02
	Wetted/wrung paper towel	8	0.13	0.72	0.18
	Item washed	46	0.77	4.13	1.03
	Non-categorized liquid emptied	15	0.25	1.35	0.34
	Non-categorized action	452	7.53	40.61	10.14
	Total	1113	18.55	100	24.97
Overall total		4457	74.28		100

IV, intravenous; EVS, environmental services.
[a] Items that were documented going to patients in observations.
[b] Items that were documented coming from patients in observations.

In addition to tracking the behaviours occurring around sinks, we tracked the items that were present when someone approached the sink. Of the 2973 videos where active sink interaction occurred, 2350 were in the patient room and 623 in the patient bathroom (i.e. non-false-positive videos). During 1018 of the patient room videos (43.3%) an item was documented by the sink prior to interaction. Items were documented by the bathroom sink in 447 (71.8%) of the videos.

Comparative analyses were completed based on room type. The total number of actions occurring in each room was compared (Figure 2a). Across all categories, the main room appears to have more actions than the bathroom, although this was not significant ($P = 0.33$, Fisher's exact test). Figure 2b shows a comparison of the percent each behaviour category represents, out of the total, for the patient room versus bathroom. The distribution is similar in the two areas, but the

Table II
Action counts and percentages for behaviours occurring at patient bathroom sinks

Group	Action name	Action count	Count per room per day	Percent group	Percent total
Medical patient care	Fill syringe or medication cup[a,b]	1	0.02	0.32	0.09
	Empty syringe or medication cup[b]	3	0.05	0.97	0.26
	Drain IV bag[b]	2	0.03	0.65	0.17
	Medical item cleaned	4	0.07	1.29	0.35
	Medical item placed	144	2.40	46.45	12.45
	Medical item removed	153	2.55	49.35	13.22
	Non-categorized medical liquid emptied	1	0.02	0.32	0.09
	Non-categorized medical behaviour	2	0.03	0.65	0.17
	Total	310	5.17	100	26.79
Non-medical patient care	Patient care item placed	7	0.12	25.00	0.61
	Patient care item removed	8	0.13	28.57	0.69
	Wetted/wrung patient rag[a,b]	13	0.22	46.43	1.12
	Total	28	0.47	100	2.42
Patient nutrition	Food/beverage placed	26	0.43	40.63	2.25
	Food/beverage removed	26	0.43	40.63	2.25
	Non-water beverage emptied	2	0.03	3.13	0.17
	Water glass filled[a]	1	0.02	1.56	0.09
	Water glass emptied[b]	9	0.15	14.06	0.78
	Total	64	1.07	100	5.53
Hand hygiene	Soap use	30	0.50	24.59	2.59
	Paper towel	63	1.05	51.64	5.45
	Hand wash	29	0.48	23.77	2.51
	Total	122	2.03	100	10.54
Environmental care	EVS staff wiped sink	40	0.67	37.04	3.46
	Non-EVS wiped sink	11	0.18	10.19	0.95
	Cleaning supplies placed	22	0.37	20.37	1.90
	Cleaning supplies removed	20	0.33	18.52	1.73
	Wetted/wrung cleaning rag	15	0.25	13.89	1.30
	Total	108	1.80	100	9.33
Additional behaviours	Personal item placed	108	1.80	20.57	9.33
	Personal item removed	109	1.82	20.76	9.42
	Non-categorized item placed	48	0.80	9.14	4.15
	Non-categorized item removed	53	0.88	10.10	4.58
	Water run	56	0.93	10.67	4.84
	Item washed	14	0.23	2.67	1.21
	Non-categorized liquid emptied	6	0.10	1.14	0.52
	Non-categorized action	131	2.18	24.95	11.32
	Total	525	8.75	100	45.38
Overall total		1157	19.28		100

IV, intravenous; EVS, environmental services staff.
[a] Items that were documented going to patients in observations.
[b] Items that were documented coming from patients in observations.

bathroom's percentages for medical patient care and hand hygiene are much lower compared to the primary patient room, and additional behaviours are more prominent in the bathroom.

Direct observation for six 4 h periods showed five instances of handwashing and nine additional behaviour types. All behaviours either came from patients or went back to patients (Table III). Two types of behaviour were associated with both directions: filled medication cups and wetted rags went to and from patients.

To gain more insight into the fluids entering the sink, we analysed the modifiers that were annotated for IV bag drainage and other beverages emptied. This analysis was only completed for the second set of videos (2748 out of 4810) resulting in the count discrepancy when compared to the totals presented earlier. Soft drink/juice was the most frequent non-water beverage category to be emptied into the sink during the analysis period. Two beverages emptied were difficult to identify due to video lighting, but cup style, opacity, and rinsing the sink or cup after emptying suggested that the liquid was a soft drink/juice. IV bags being emptied were equally small or medium in size and half of the observed IV bags were full or mostly full. Frequency counts for these sub-categorizations are documented in Supplementary Table II.

Discussion

This study has described sink usage in a single MICU over a 60-day period and found that the majority of activities were

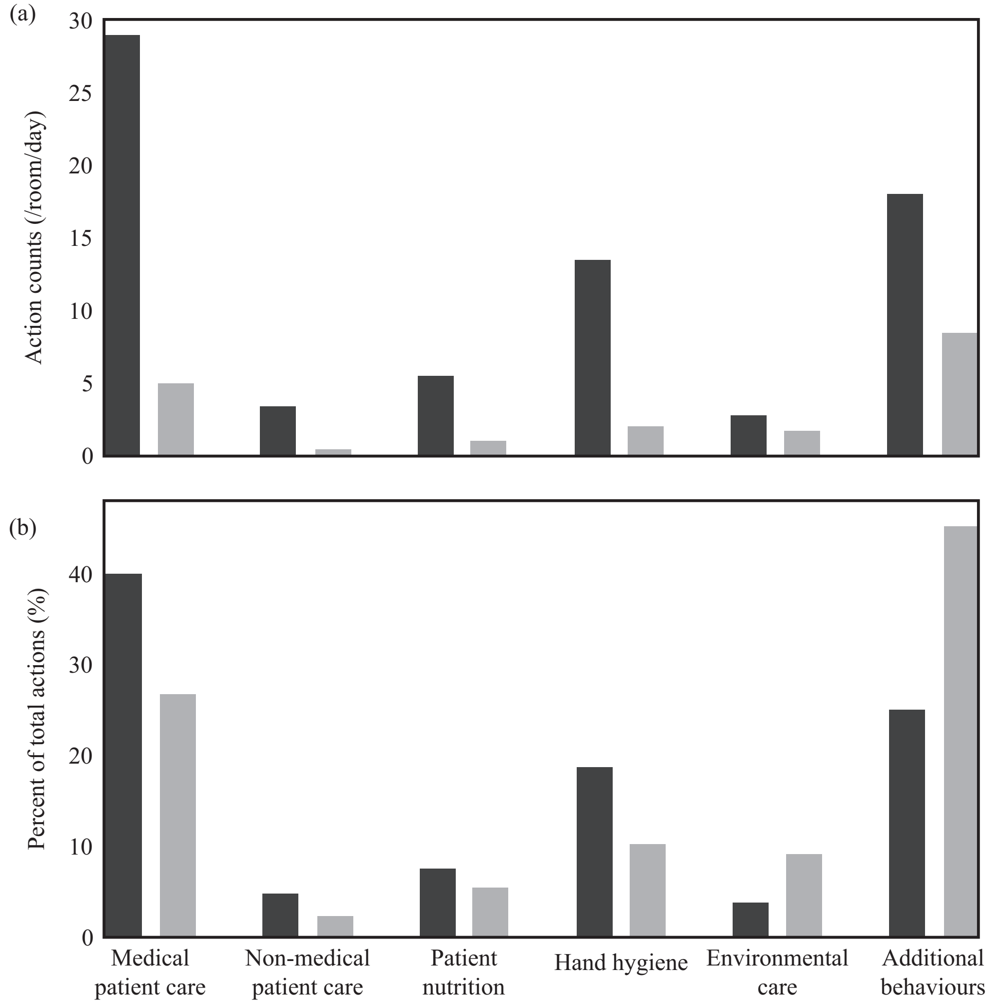

Figure 2. (a) Comparison of action counts per room per day for patient rooms (black bars) and bathrooms (grey bars). (b) Comparison of each behaviour category's relative percent in patient rooms and bathrooms.

Table III
Behaviour counts and item directionality from direct observations

Action	Count	Medical (Y/N)	No. to patient	No. from patient
Cup emptied	1	N	0	1
IV bag drained	1	Y	0	1
Medication cup filled	6	Y	5	2
Medication cup washed/emptied	3	Y	0	3
Syringe washed/emptied	1	Y	0	1
Paper towel	1	N	1	0
Rag wetted	4	N	4	2
Item placed	2	N	0	2
Item removed	2	N	2	0

IV, intravenous.

not hand hygiene-related. Several activities involved behaviours that would potentially enhance growth of a biofilm in the drain or allow for contamination of patient items which are then used for patient care. This helps to explain the role that sink behaviour could have in transmission of organisms from an environmental reservoir to a patient.

Use of anonymized cameras allowed us to capture a larger dataset and, because of the long time-frame, the Hawthorne effect may have waned. Camera footage was also paired with on-site observations which allowed for an understanding of item directionality in patient rooms as well as validation of camera functionality. During direct observations, it was noted that most behaviours occurring around sinks involved movement either to or from the patient. This fact may play an important role in facilitating contaminated items moving between patient and sink. Using this analysis to understand how the patient–provider–sink chain occurs may assist in identifying paths or mechanisms that could be modified and thus may help reduce transmission of multidrug-resistant Gram negatives in hospitals.

Annotation of videos from 60 patient room-days and 60 patient bathroom-days showed many different behaviours occurring around sinks. The hand hygiene category in this analysis accounted for about 20% of main room and 10% of bathroom activities. Handwashing was less than 5% of all behaviours (note: this does not indicate poor hand hygiene compliance as alcohol rub is an alternative method). Anecdotally, the hand hygiene use of the sinks increased markedly when a *C. difficile* patient was admitted to the room, but these days did not have complete data and were eliminated from the analysis. Whereas we anticipated behaviours outside of hand hygiene to occur, the relative importance of this category was unexpected. Sinks were initially placed in every ICU patient room so that there would be availability to wash hands with every encounter [15]. The importance of proximity of locations to practice hand hygiene has been evaluated and location remains significant [16,17]. However, with the increase in alcohol for hand hygiene the sink may not play the same role, especially with frequency, and it may be time to recalculate the risk/benefit of having a sink in an ICU room [3].

Other research has noted that the use of sinks for medication disposal, fluid drainage, and medical preparation guidelines do not address the issue of 'by-sink' prep [9,18–20]. If the need for a sink in a room is driven by factors besides hand hygiene it may be important to evaluate what other activities would need to be supported. A recent study demonstrated a decrease in transmission of drug-resistant Gram-negative bacteria by making the ICU rooms 'waterless' [3]. The high numbers of non-hygiene behaviours occurring at sinks suggests a need for improving guidelines on sink usage and placement. As this project was completed as a quality investigation to assess what behaviours were potentially contributing to CPE in the drains, we provided feedback to unit staff that patient care items should be removed from around the sink, as this has been noted to be high risk for transmission. This education had occurred prior to the video placement and in following data review, but was not prospectively audited outside of this study.

Our analysis on frequency of item presence at the sink showed one or more items were present 43% of the time an individual approached the main room sink and 71% in the bathroom sink. These data suggest that sink counters in this ICU design are frequently used as storage space, likely because there is limited horizontal work space to store items until ready for use. A head-mounted camera study recently tracked the number of connections healthcare workers have with the environment and patient: surface touching occurred every 4.2 s, adding increased awareness to interplay between healthcare workers and potentially contaminated items in the patient care environment [21]. Increasing availability of alternative horizontal surfaces for providers and patient families along with a clear description of what each surface should be used for may decrease usage of sink counters for storage purposes.

Several behaviours recorded may influence bacterial transfer, growth in sinks, and development of antibiotic resistance. It is also noted from others' work that sinks are used for waste disposal, but this was not likely the original intent [15]. Unique to a healthcare environment is an increased exposure to multidrug-resistant bacteria that may be seeded into the drain and provided nutrients which appear to be critical to the robustness or the load and potentially even dispersion [10]. We observed disposal of antimicrobials, patient nutrition items, and intravenous fluid which could provide nutrients and selective pressure. Contaminated sink drains have been documented in several hospital outbreaks, and understanding how bacteria invade sinks and thrive is important for improving prevention measures [9,11,22]. Continued research into the nutrients bacteria obtain through normal sink usage will be important for determining how to interact with sinks to avoid the promotion of biofilms containing highly resistant bacteria such as *Pseudomonas aeruginosa* or CPE, which can survive in the environment [4].

Our pilot project had several limitations that should be considered. The primary limitation was that this was a single medical ICU room layout and would need to be repeated in other settings with different layout and availability of horizontal surfaces. Comparability between bathroom and main room cameras is limited due to the difference in counter space and sink usage (Figure 1b, c), but we felt that this provided additional data around differing types of sink usage, even though confined to similar room layouts and patient mix. Another limitation was the camera network and server connectivity issue mentioned in the Methods section. Due to the large amount of data being transmitted and stored, the storage server would stop saving new footage and there was inconsistent network connectivity. As was previously stated, the selection of days used in this analysis was completed based on estimates of server and camera functionality. If gaps between recordings were too long, that day of footage was excluded from analysis. During the 24 h of direct observation it was noted that one direct observation was not caught on camera. As annotations were completed, lack of footage corresponding to item arrival by (or removal from) the sink was also noted several times (exact number not tracked) despite consistent connectivity.

Video analysis of behaviours around ICU sinks shows predominance of non-hand hygiene behaviours occurring at patient sinks. Medical behaviours and non-water liquids emptied into sinks may play an important role in acquisition and maintenance of bacteria in sink drains. Use of these surfaces for storage may also encourage transmission of bacteria to other reservoirs. As we have attempted to further define the potential role of hospital sinks as a reservoir for multidrug-resistant Gram-negative bacteria, it has been critical to understand the behaviours that occur around the sink. Many of the witnessed sink activities could promote transmission and propagation; thus we may need to reconsider the intent and placement of sinks in a patient ICU room as well as the importance of providing clear guidance for healthcare worker activity with sinks.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.jhin.2018.04.025.

Conflict of interest statement
None declared.

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References

[1] US Centers for Disease Control and Prevention. Antibiotic resistance threats in the United States, 2013. CDC, US Department of Health and Human Services; 2013.
[2] World Health Organization. Antimicrobial resistance: a global report on surveillance. 2014.
[3] Hopman J, Tostmann A, Wertheim H, Bos M, Kolwijck E, Akkermans R, 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.
[4] Kizny Gordon AE, Mathers AJ, Cheong EY, Gottlieb T, Kotay S, Walker AS, 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;64:1435–44.
[5] Walsh TR, Weeks J, Livermore DM, Toleman MA. Dissemination of NDM-1 positive bacteria in the New Delhi environment and its implications for human health: an environmental point prevalence study. Lancet Infect Dis 2011;11:355–62.
[6] Sheppard AE, Stoesser N, Wilson DJ, Sebra R, Kasarskis A, Anson LW, et al. Nested Russian doll-like genetic mobility drives rapid dissemination of the carbapenem resistance gene blaKPC. Antimicrob Agents Chemother 2016;60:3767–78.
[7] Vergara-López S, Domínguez M, Conejo M, Pascual A, Rodríguez-Baño J. Wastewater drainage system as an occult reservoir in a protracted clonal outbreak due to metallo-β-lactamase-producing *Klebsiella oxytoca*. Clin Microbiol Infect 2013;19:E4908.
[8] Tofteland S, Naseer U, Lislevand JH, Sundsfjord A, Samuelsen Ø. 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.
[9] Lowe C, Willey B, O'Shaughnessy A, Lee W, Lum M, Pike K, et al. Outbreak of extended-spectrum beta-lactamase-producing *Klebsiella oxytoca* infections associated with contaminated hand-washing sinks. Emerg Infect Dis 2012;18:1242–7.
[10] 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 hand-washing sink-trap reservoirs. Appl Environ Microbiol 2017;83. pii: e03327-16.
[11] Roux D, Aubier B, Cochard H, Quentin R, van der Mee-Marquet N. Contaminated sinks in intensive care units: an underestimated source of extended-spectrum beta-lactamase-producing Enterobacteriaceae in the patient environment. J Hosp Infect 2013;85:106–11.
[12] McBain AJ, Ledder RG, Moore LE, Catrenich CE, Gilbert P. Effects of quaternary-ammonium-based formulations on bacterial community dynamics and antimicrobial susceptibility. Appl Environ Microbiol 2004;70:3449–56.
[13] Grabowski ME, Kang H, Wells KM, Sifri CD, Mathers AJ, Lobo JM. Provider role in transmission of carbapenem-resistant Enterobacteriaceae. Infect Control Hosp Epidemiol 2017;38:1329–34.
[14] Mathers AJ, Vegesana K, German Mesner I, Barry KE, Pannone A, Baumann J, et al. Intensive care unit wastewater interventions to prevent transmission of multi-species *Klebsiella pneumoniae* carbapenemase (KPC) producing organisms. Clin Infect Dis 2018 Feb 2. https://doi.org/10.1093/cid/ciy052 [Epub ahead of print] PMID:29409044.
[15] Thompson DR, Hamilton DK, Cadenhead CD, Swoboda SM, Schwindel SM, Anderson DC, et al. Guidelines for intensive care unit design. Crit Care Med 2012;40:1586–600.
[16] Dufour J, Reynier P, Boudjema S, Aladro AS, Giorgi R, Brouqui P. Evaluation of hand hygiene compliance and associated factors with a radio-frequency-identification-based real-time continuous automated monitoring system. J Hosp Infect 2017;95:344–51.
[17] Stackelroth J, Sinnott M, Shaban RZ. Hesitation and error: does product placement in an emergency department influence hand hygiene performance? Am J Infect Control 2015;43:913–6.
[18] Donn J, Mendoza M, Pritchard J. Health facilities flush estimated 250M pounds of drugs a year. USA Today; 2008. p. 14.
[19] Nettina SM, Msn A. Lippincott manual of nursing practice. Philadelphia: Lippincott Williams & Wilkins; 2013.
[20] Centers for Medicare & Medicaid Services, Department of Health and Human Services. Condition of participation: nursing services. 42 CFR.482.23. 2002.
[21] Wolfensberger A, Sax H, Clack L, Scotoni M. "First-person view" of pathogen transmission and hand hygiene – use of a new head-mounted video capture and coding tool. Antimicrob Resist Infect Control 2017;6:108.
[22] Dancer SJ. Importance of the environment in methicillin-resistant *Staphylococcus aureus* acquisition: the case for hospital cleaning. Lancet Infect Dis 2008;8:101–13.