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Short Report

Impact of sink design on bacterial transmission from hospital sink drains to the surrounding sink environment tested using a fluorescent marker

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SUMMARY

In hospitals, sinks act as reservoirs for bacterial pathogens. To assess the extent of splashing, fluorescein dye was added to four hospital sinks previously involved in pathogen dispersal to the environment and/or transmission to patients, and one sink that was not. Applying dye to the p-trap or tailpiece did not result in any fluorescent droplets outside of the drain. When applied to the drain, droplets were found in all but one wash basin, and this was more common in the absence of a drain plug. Sink design considerations to install drain plugs, reduce dripping and offset the tap may help to prevent transmission from drains.

Introduction

In recent decades, the role played by the healthcare environment in the transmission of bacterial pathogens has been elucidated increasingly [1–3]. Sink drains have been identified as important reservoirs for multi-drug-resistant Gram-negative bacteria [2,3]. Here, bacteria form biofilms in pipe lumens, from which cells may be released during sink use and spread outside of drains within droplets or as aerosols [4–6]. As a result, surfaces in the innate patient environment may become contaminated, which may lead to nosocomial transmission and outbreaks [3]. Bacterial drain reservoirs are often difficult to eradicate, as commonly used hospital disinfectants have limited efficacy on these biofilms, and recolonization may occur

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after exposure to contaminated materials or retrograde growth from p-traps [5,7].

At Erasmus MC University Medical Centre, environmental sampling was initiated in 2011 when cases of Verona Integron-encoded Metallo-beta-lactamase-positive *Pseudomonas aeruginosa* (VIM-PA) emerged in patients. Ensuing studies uncovered high concentrations of this bacterium in some sink drains on patient wards, and sporadically on wash basins and surrounding surfaces [8]. In 2018, a new building for patient care was opened, and all of the old wards were permanently closed. As environmental sampling data were available from these closed wards, the authors had the unique opportunity to salvage complete sink setups from rooms where VIM-PA dispersal from the sink to the environment, and/or transmission from the sink to a patient, had occurred. The aim of this study was to identify the extent that sink design affected splashing – focusing on tap position, wash basin shape, and the presence or absence of a drain plug – that may have contributed to these past transmission events.

Methods

Setting and sink selection

Erasmus MC University Medical Centre is a large, tertiary care hospital in Rotterdam, The Netherlands. In 2018, patients were moved to a newly constructed building, and use of the old patient wards was discontinued. Five sinks were salvaged from these closed wards. Four sinks were selected based on the following criteria: (i) known colonization of VIM-PA in the drain and prior involvement in dispersal to the surrounding sink environment and/or transmission to a patient; and (ii) a unique design/tap position compared with the other sinks. Sink 1 was from a patient isolation room in an adult intensive care unit (ICU), and was composed of a stainless steel, flat-bottomed wash basin, and a tap positioned so that water did not land directly in the drain. Sink 2 was from a patient room on the gastrointestinal surgery ward, and Sink 3 was from a patient room bathroom on the haematology ward; both Sinks 2 and 3 were composed of a ceramic, curved wash basin where water did not land directly in the drain. Sink 4 was from a dirty utility room for healthcare workers on the vascular surgery/renal transplantation ward, and was composed of a stainless steel, flat-bottomed wash basin where water landed directly in the drain. Sink 5 was selected because VIM-PA had never been cultured from the drain before; this sink was located in the anteroom of the adult ICU patient isolation room where Sink 1 was located, and the wastewater pipelines of these sinks had been connected. Compared with Sink 1, Sink 5 was similarly composed of a stainless steel, flat-bottomed wash basin, but the tap was offset from the drain. Images of the five sinks with tap positions are available in Figure S1 (see online supplementary material).

All five sinks, while different in design and composition, had drains with a built-in strainer positioned at the base of the wash basin, and were completely covered by identical stainless steel drain plugs (Article no. UD.526.51; Raminex, Utrecht, The Netherlands).

Splashing dynamics

Three sites were dyed per sink: the p-trap; the drain beneath the strainer; and the tailpiece (a pipe connecting the p-trap to the drain). For the p-trap, residual water was emptied, and a fluorescent solution containing 0.5 g fluorescein powder (Uranine, Trotec GmbH, Heinsberg, Germany) dissolved in 60 mL tap water was added to simulate a contaminated water reservoir (Figure S2, see online supplementary material). For the tailpiece and the drain, a fluorescent paste containing 3 g fluorescein powder dissolved in 1 mL tap water was applied to the lumen of the tailpiece or underneath the drain strainer, respectively, to simulate bacterial biofilm. Water was supplied to taps at a pressure of 3.2 bar for 120 s per experiment. Ultraviolet light was used to visualize fluorescent drops. Droplet distance was measured from the centre of the drain to the location of the furthest observed droplet. Remaining fluorescein was removed before each new experiment. Experiments were repeated five times per contamination site per sink.

Results and discussion

This study investigated four sinks from patient wards with unique designs that had previously been involved in VIM-PA transmission, and one sink that had never been colonized by VIM-PA, to test the distance and frequency of splashing from the drain to the surrounding sink environment.

For each sink, the p-trap was dyed, but after running the tap, no fluorescence was observed outside of the drain in any of the sinks (Table I). Similarly, no fluorescence was observed outside of the drain in any sink when the tailpiece was dyed. However, fluorescent residue was discovered in the tailpiece threads of Sink 2 after dismantling.

The drain was subsequently dyed either with or without a drain plug present. With drain plugs installed, fluorescent droplets were found outside of the drain in Sinks 1, 2 and 4, but most frequently in Sink 4 (Table I). In Sink 4, fluorescent droplets were found underneath the drain plug, and dripped on to water that had not drained immediately, resulting in at least one droplet found 150 mm from the drain. In general, when Sink 4 experienced slow drainage, water running/dripping from the tap was seen to push dye further from the drain instead of washing it away. In Sink 1, a fluorescent droplet found 80 mm from the drain was caused by water dripping from the tap after it had been turned off.

When drain plugs were removed, fluorescent droplets were found outside of the drain in Sinks 1, 2, 3 and 4, but most frequently in Sink 4. In Sink 1, dripping from the tap resulted in a fluorescent droplet found 140 mm from the drain. In Sink 2, water spraying from the tap resulted in a fluorescent droplet found 160 mm from the drain. In Sink 4, a large pool of fluorescent residue was created in the wash basin due to dripping when the tap was turned both on and off; additionally, the furthest droplets observed in all Sink 4 experiments were found on the walls of the wash basin directed toward the sink user. Overall, of the 25 experiments performed without a drain plug and 25 experiments performed with a drain plug, a significant reduction in dispersal was observed when a drain plug was present (13/25 vs 5/25; P=0.04 using Fisher's exact test).

No fluorescence was found beyond the wash basin in this study. Additionally, no fluorescence was observed outside of the drain of Sink 5, irrespective of the presence of a drain plug. Examples of fluorescent droplets seen in experiments with/

Table I

Characteristics of the five tested sinks, and dispersal observed outside the drain per contamination site per sink

	Sink 1					Sink 2					Sink 3					Sink 4					Sink 5				
Ward	Adult ICU					Gastrointestinal surgery					Haematology					Vascular surgery/renal transplantation					Adult ICU				
Room type	Patient isolation room					Patient room					Patient room bathroom					Dirty utility room					Anteroom of patient isolation room (where Sink 1 was located)				
Sink users	Healthcare workers and visitors					Healthcare workers and patients					Healthcare workers and patients					Healthcare workers and cleaning personnel					Healthcare workers and visitors				
History of VIM-PA transmission	Yes					Yes					Yes					Yes					No				
Material of wash basin	Stainless steel					Ceramic					Ceramic					Stainless steel					Stainless steel				
Wash basin shape	Flat-bottomed, circular basin					Curved bottom, oval basin					Curved bottom, oval basin					Flat-bottomed, rectangular basin					Flat-bottomed, circular basin				
Wash basin depth (mm)	140					150					150					150					140				
Tap location and relative position to drain	Integrated in countertop; water landed next to the drain					Attached to the wall; water landed in the wash basin away from the drain					Attached to the wall; water landed next to the drain					Attached to the wall; water landed directly in the drain					Integrated in countertop; offset from drain; water landed in the wash basin away from the drain				
Contamination site																									
P-trap (no drain plug present)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tailpiece (no drain plug present)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Drain with plug	-	-	-	-	+	+	-	-	-	-	-	-	-	-	-	-	+	-	+	+	-	-	-	-	-
Distance furthest droplet (mm)					80	60											60		60	150					
Drain without plug	+	+	+	+	-	-	-	+	-	-	+	+	+	-	-	+	+	+	+	+	-	-	-	-	-
Distance furthest droplet (mm)	140	90	40	70				160			150	160	150			150	120	150	100	140					

VIM-PA, Verona Integron-encoded Metallo-beta-lactamase-positive *Pseudomonas aeruginosa;* ICU, intensive care unit; +, fluorescent droplets were found in the wash basin; -, no fluorescent droplets were found in the wash basin.
Results from five replicates are shown for each sink.

without drain plugs are shown in Figure S3 and Movie S1 (see online supplementary material).

Supplementary video related to this article can be found at https://doi.org/10.1016/j.jhin.2022.04.017

These findings contribute to a body of accumulating evidence that colonization of sink drains may lead to the dispersal of micro-organisms from drains, but not from p-traps or tailpieces. Applying dye to the drain yielded visible artificial contamination in the wash basins of all but one sink, and this was more common in the absence of a drain plug.

Fluorescence outside of the drain was observed more often in Sinks 1, 3 and 4. The tap of Sink 4 was positioned directly over the drain, which may have contributed to the fact that the furthest observed droplets when no drain plug was present were found on the walls of the wash basin. Sinks 2 and 5 had identical designs to Sinks 3 and 1, respectively, with the exception that water landed in the wash basin further from the drain. By increasing the distance that water needed to travel to the drain, few instances of droplet dispersal from the drain of Sink 2 were observed, and a complete lack of dispersal from the drain of Sink 5 was observed. These results reinforce previous reports that taps positioned directly over drains make the greatest contribution to dispersal from drain reservoirs [9]. Moreover, all wash basins in this study had relatively shallow depths, between 140 and 150 mm, which has previously been found to be a significant risk factor for dispersal [10]. Finally, the taps of Sinks 1 and 4 were frequently observed dripping, which directly caused fluorescent droplets to disperse from the drain; the flat-bottomed wash basins of these sinks permitted drips to spread further from the drain with increasing water pressure. This effect was not observed in experiments with curved wash basins (Sinks 2 and 3), as these basins had a smaller radius of spreading water and drained more quickly.

In this study, drain plugs showed a positive, significant effect of limiting the incidence and distance of splashes. However, fluorescent residue was found in the drain plug threads of Sinks 2 and 5 after dismantling, indicating potential for the drain plug/threads to provide a surface on which biofilms may form and harbour pathogens. Nevertheless, as running water does not usually reach this location, dispersal from this site is unlikely, but monitoring and periodic cleaning of the drain plug by trained personnel should be considered.

In the study hospital, the wastewater pipelines between Sinks 1 and 5 had been connected, but VIM-PA had never been detected in Sink 5. Sink 5 belonged to the anteroom of a patient room, so it is possible that this sink was exposed to colonized patients/contaminated materials less frequently, and patients were less likely to be exposed to this sink. In a previous study that investigated drain microbiota, the drain of Sink 5 (Drain E^- in that study) had comprised high relative concentrations of *Candida albicans* and *Lactobacillus* spp. that were lacking in the microbiota of the drain of Sink 1 (Drain C^+), so it is possible that the presence of these micro-organisms in the drain of Sink 5 resisted colonization by VIM-PA [8]. Therefore, other factors besides sink design may have contributed to the observation that Sink 5 was never involved in VIM-PA transmission.

This study had some limitations. Few sinks/sink designs were tested, but the sinks were selected based on known transmission events, and had slight differences in tap position that made them interesting candidates for comparison of dispersal. Additionally, no micro-organisms were used during the study; a fluorescent marker was applied to the sinks to simulate bacterial contamination, but it is unknown how representative this marker was of bacterial sink biofilms with regards to viscosity or adherence to sink materials, or how it compared with previously used fluorescent markers [4,5,10]. Using a micro-organism-free approach also meant that other factors, such as nutrient exposure, moisture level, disinfectant efficacy or biofilm maturity, could not be included as test parameters.

In hospitals, sink placement is more often influenced by non-medical sources than medical sources (e.g. facility management, installation advisors). This study highlighted good practices for limiting dispersal from contaminated drains by making small changes to existing sinks. However, these findings may also aid in impacting future design/placement choices to create safer healthcare environments for both personnel and patients.

In conclusion, it is recommended that decolonization efforts should focus on cleaning or preventing the colonization of drains/strainers, as these sites are more likely to be a source of pathogen dispersal from sinks than p-traps and tailpieces. Installing drain plugs, reducing dripping from taps, and offsetting taps and/or drains so that water does not land directly in the drain may also help prevent dispersal from drains. However, more experiments are needed using bacteria instead of surrogate markers on a larger number of sinks/designs to produce more firm conclusions on the impact of sink design on contaminating the surrounding sink environment.

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Author contributions

MV obtained funding and managed the project. TS, JS and MV conceived and designed the study. TS executed the experiments. JP, TS, JS and MV analysed and curated the data. JP wrote the manuscript. All authors read and critically revised the manuscript, and approved the final manuscript.

Conflict of interest statement

TS and MH work for companies involved in healthcare design. All other authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhin.2022.04.017.

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