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Mitigation of microbial contamination from waste water and aerosolization by sink design

K. Cole, J.E. Talmadge*

Department of Pathology and Microbiology, University of Nebraska Medical Center, Omaha, NE, USA

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SUMMARY

Background: Healthcare-associated infections (HAIs) are a significant cause of increased medical costs, morbidity, mortality, and have been partly associated with sinks, their waste water outlets and associated pipework.

Aim: To determine whether an engineered sink could limit microbial aerosol contaminants in the air and sink basin.

Methods: Multiple comparisons were undertaken between an experimental sink, designed to limit aerosolization and p-trap contamination to a control hospital sink, both connected to a common drain system. The experimental sink was equipped with ultraviolet light (UV), an aerosol containment hood, ozonated water generator and a flush system to limit bacterial growth/aerosolization and limit microbial growth in the p-trap. Nutrient material was added daily to simulate typical material discarded into a hospital sink. Surface collection swabs, settle plates and p-trap contamination levels were assessed for bacteria and fungi.

Findings: The experimental sink had significantly decreased levels of bacterial and fungal p-trap contamination (99.9% for Tryptic Soy (TSA) and Sabouraud agar (SAB) plates) relative to the initial levels. Aerosol-induced contaminant from the p-traps was significantly lower for the experimental vs the control sink for TSA (76%) and SAB (86%) agar settle plates.

Conclusions: Limiting microbial contamination is critical for the control of nosocomial infections of in-room sinks, which provide a major source of contamination. Our experimental sink studies document that regular ozonated water rinsing of the sink surface, decontamination of p-trap water, and UV decontamination of surfaces limits microbial aerosolization and surface contamination, with potential to decrease patient exposure and reduce hospital acquired infections.

Introduction

Healthcare-associated infections (HAIs) in hospitals are a significant cause of morbidity and mortality. In 2002, the estimated number of HAIs in US hospitals, including federal facilities, was approximately 1.7 million individuals [1]. Adverse events from the HAIs included an estimated 98,987 deaths in US hospitals with 35,967 secondary to pneumonia, 30,665 bloodstream infections, 13,088 urinary tract infections, 8205 surgical site infections, and 11,062 infections at other sites. The overall annual direct medical costs of HAIs to US

* Corresponding author. Address: University of Nebraska Medical Center, Omaha, NE 68198-6495, USA. Tel.: +1 402 559 5639.
E-mail address: jtalmadg@unmc.edu (J.E. Talmadge).

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hospitals has been estimated to range from $28.4 to $33.8 billion [2].

The clinical environment can facilitate transmission of healthcare-associated pathogens, including vancomycin-resistant enterococci (VRE), *Clostridium difficile*, *Acinetobacter* spp., meticillin-resistant *Staphylococcus aureus* (MRSA) and norovirus [3,4]. These frequently-shed pathogens arise from patients, staff and contaminated surfaces, increasing the risk of infection [5,6]. Environmental monitoring confirms contamination of equipment, and the hospital room environment in patient infection, and often occurs throughout clinical areas in a healthcare facility [7]. The biofilm(s) that are present in wastewater pipes are difficult to eradicate by conventional means [8]. Several approaches have been investigated to reduce the microbial bioburden, including fixture replacement and disinfectants.

Despite reports [9,10] that hand-washing sinks can act as microbial reservoirs contributing to nosocomial infections, control of this contamination source has frequently been overlooked. Indeed, there has been a marked increase in sink related outbreaks, with many studies establishing an observational link [11—14]. A sink, often in the same room as the patient, can operate as an open conduit to waste water [15]. The routine method to control environmental-related transmission is enhanced cleaning with chemical and physical agents [16,17]. Unfortunately, routine approaches are inefficient in eliminating microbes in inaccessible areas, such as sink traps [13,16,18—21]. This wet, humid and relatively protected environment, as well as the presence of waste fluid nutrients, favors the formation of a rich stable microbial community known as a biofilm and can also provide a source of microbial aerosols [16,22,23]. In short, sink traps are a source for opportunistic and antimicrobial resistant bacteria, which cannot be easily controlled or removed [24—27].

Indeed, there have been numerous reports of sinks and p-traps acting as sources of virus, bacteria and fungi during nosocomial outbreaks [28]. Plumbing traps, including p-traps, filter the smell of sewer gases rising from the sink drain into a building. Interdisciplinary studies, that include engineers and microbiologists, are needed to establish guidelines for sanitation strategies to achieve improved infection control via architectural design and maintenance practices. To accomplish this goal, three aspects, important to infection control, must be established: (1) detection of pathogen containing aerosols and surface contaminants; (2) evaluation and improvement of current sink architectural designs from an infection-control perspective; and (3) improved maintenance practices with a focus on optimization.

Despite the best efforts of hospitals to maintain a clean patient environment, there is evidence of pathogenic microbes within sinks in patient rooms [14,20,21,29—31], that occurs due to the connection of a sink to its draining system secondary to retrograde microbial spread from the sewer to the p-trap [15,32]. Herein, our initial studies into the efficiency of a novel sink design to limit nosocomial infections are reported. The sink incorporates an ozonated water generator that regularly sprays the basin behind the sink hood, providing a flush of the drain and p-trap water, a hood that establishes a negative pressure environment to control aerosols, and an ultraviolet (UV) light to kill any surrounding bacteria. The use of this sink, as compared to a control sink, is studied in a longitudinal study to significantly reduce contamination via sink aerosols, p-trap level, and room air contaminant, although the latter is of lesser concern.

Materials and methods

In this study, an experimental sink of novel design (23.5" × 19" × 14″ with the water impact surface 5.3″ below the flood rim of the sink) was compared to a standard stainless steel 22″ wide × 19″long × 7 and 5/8″ deep sink (control sink) that is installed in many locations throughout the hospital. The water outlet discharged above the sink, such that the water stream hit the sink basin just behind the grid strainer. The exact same faucet was used on both the standard sink and the prototype sink, the faucets were single-hole, infrared-sensor battery-operated, 1.5 gallons per minute flow, with laminar flow non-aerated outlets, adjustable external thermostatic mixing valves, and 12″ gooseneck spouts with the outlet discharging 7″ above the flood rim of the sink. When the faucets were activated, they were programmed to flow water for 30 s. For the study, the control sink was disinfected using abrasion, hot water, and Sporklenz cleaner (Steris Corp, St. Louis, MO, USA), and the plumbing for the control sink replaced to the vertical

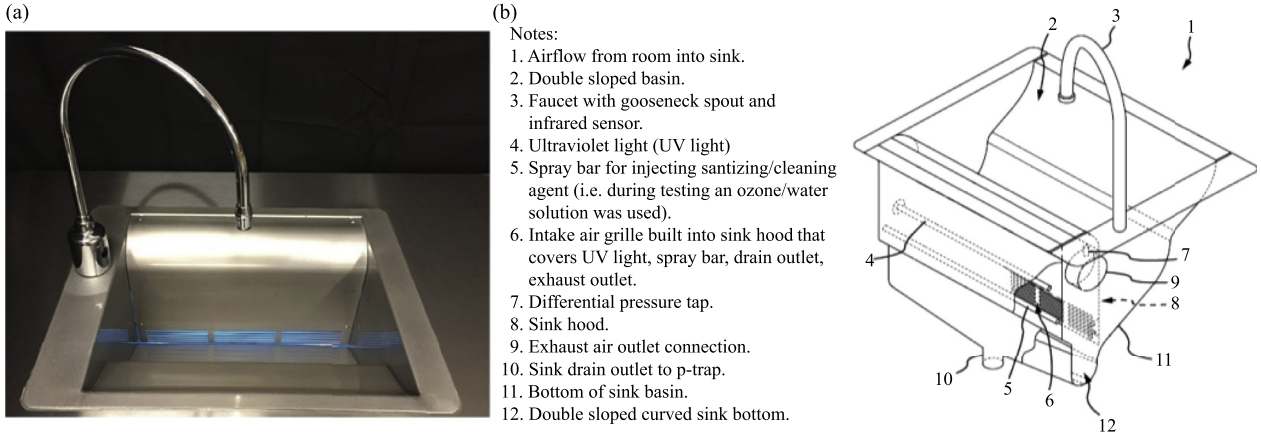

Figure 1. (a) Photograph of the experimental sink, dimensions of 23.5" × 19" × 14″ with the water impact surface location of 5.3″ below the flood rim of the sink. Note the germicidal ultraviolet light. (b) Schematic of the experimental sink.

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stack, prior to experimentation. Sporklenz is a stabilized blend of peracetic acid, hydrogen peroxide, and acetic acid with sporicidal activity for sterilization of environmental surfaces. The experimental sink (Figure 1) was constructed of powder-coated 22-gauge stainless steel with a unique basin profile that included a rear wall, engineered to reduce water splashing with use. This rear wall was constructed from 20-gauge stainless steel with a grid that was laser cut into in the lower 3″ of the wall for airflow, the wall stopped 1/8″ from the lower basin surface for fluid drainage of the basin. The distance between the end of the outlet and the top of the basin (flood rim) is the same as the standard sink. Behind this wall housed a negative pressure venting system, a germicidal UV light, and a spray bar that allowed for an ozonated water flush system. The venting system pulled air from the rear portion of the sink to vent externally, creating a linear draw rate in excess of 100 ft/min at the rear wall grid. A bar-type germicidal UV-C light high-output bulb (approximately 37 W) with an intensity of 56 μW/cm^2 at 1 m was placed horizontally across the rear wall. The UV light radiation levels were measured against the outlet of the intake grill and along the perimeter of the slight gap between the hood and the sides of the sink, and in all locations levels were found to be lower than the permissible 8-h dose of 6.0 mJ/cm^2 for 254 nm wavelength, as determined by the National Institute for Occupational Safety and Health. Below the UV-C bulb, a stainless-steel spray bar with spray openings, spaced along the shaft, rinsed the area between the light and the drain with ozonated water for 1 min, every 30 min, at a rate of one gallon per minute. Ozonated water provides two mechanisms of microbial control, dilution/washing and antimicrobial activity. Because of the potential for dilution to have a role in control of contamination, a similar timed automated faucet was installed on the control sink and initiated following the three-day contamination stabilization. The ozonated water was created using an ozone-generator system designed to produce ozone at a concentration of 1.0 part per million. The ozone production by the generator system was validated at the beginning and end of the study. The experimental sink was located approximately 24″ horizontal to the edge of the control sink, and a 4-ft-tall and 3-ft-deep plexiglass barrier was placed between the sinks to reduce cross-contamination between sinks. New chromed brass tailpipes of 1½” diameter p-traps were installed on each sink with new 40 polyvinylchloride (PVC) waste lines attached. The waste lines merged 60″ from the experimental sink trap and 24″ from the control sink trap, and were connected with a Y-fitting to the building sanitary line, approximately 12″ from the Y-fitting connection.

Experimental design

Three 11-day experiments were conducted using Day 1 as the baseline. Due to the formation of a mycelial mat in the trap of the control sink, on completion of each experiment, both sinks were cleaned and biomass reduced with boiling water followed by Sporklenz to reduce microbial contamination and establish a standardized baseline. This was undertaken on both the control and experimental sinks. To ensure a common level of contamination, wastewater was obtained from distant municipal and hospital sinks and an equal volume added to the p-trap of each sink. A sample taken at this time provided a baseline microbial contamination level for the p-trap. A four-day incubation period for both the experimental sink and control sink was conducted after the initial addition of the p-trap water and prior to initiating the periodic spraying with ozonated (experimental sink) or facility water (control sink). To replicate typical hospital waste addition to the sinks, 50 mL of Ensure (Abbott Laboratories, Irving, TX, USA) was added daily to both sinks at a 1:9 dilution. To assess the role of dilution with water vs ozonated water, an automated rinse was also established for the control sink with identical timing to the experimental sink.

Microbial analysis

In these studies, p-trap samples were obtained using a sterile 36″ microbore extension set (Advances Medical Systems) and, a 5-ml syringe (Becton Dickinson and company (BD) syringe, Franklin Lakes, NJ, USA), with the p-trap water mixed by expressing the water in the trap 10× prior to collection and multiple serial dilutions undertaken. Each sample was subjected to a 1:10 serial dilution and 100 uL of each dilution was spread using a sterile glass spreader on both TSA (BD, Sparks,

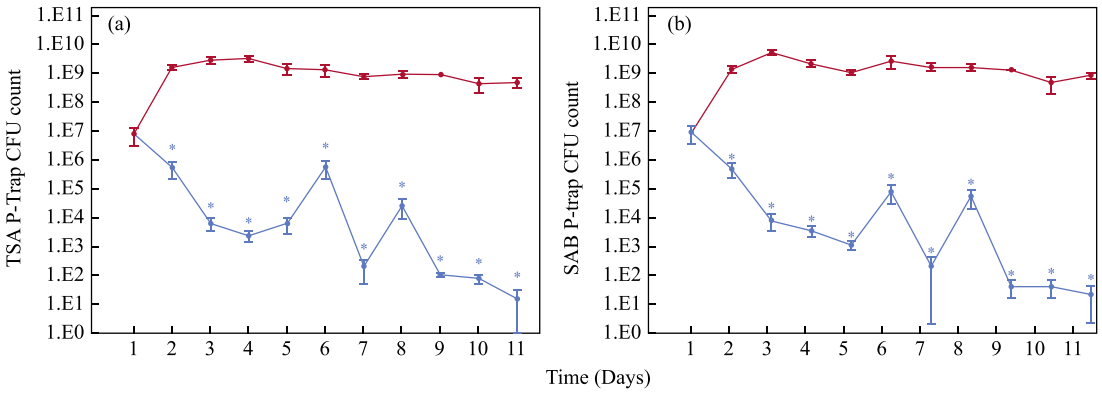

Figure 2. Pooled data (N=3) of P-trap colony-forming unit (cfu) count on Tryptic Soy (TSA) and Sabouraud agar (SAB) for the control vs the experimental sink. (a) When comparing the average cfu counts for TSA p-trap data of the experimental vs the control sink, the data was found to be statistically significant (P<0.05) on Days 2—11. (b) Pooled data (N=3) for the cfu count for SAB p-trap data for the control and experimental sink. When comparing the cfu count for the control vs the experimental sink, the data was statistically significant (P<0.05) on Days 2—11.

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MD, USA) and SAB (BD, Sparks, MD, USA) plates with an n of 2, prior to room-temperature incubation. The number of bacteria was calculated using the dilution that resulted in less than 300 colonies. The settle plates were exposed for 4 h, with three TSA and three SAB plates exposed on the counter edge and on the bottom of the sink basin. The Copan culture swabs (BD, Italy) were collected on the right of the control sink basin and at the center of the experimental sink basin. Culture swabs were vortexed and placed within a biological safety level (BSL) hood for sterile transfer to a sterile 15-mL labeled tube (Falcon, Tamaulipas, Mexico) before being diluted 1:20 and 1:100 in Hank's balanced salt solution (HBSS) (Gibco, Grand Island, NY, USA) and two plates spread for each sample. The number of colony-forming units (cfu) on the TSA plates were counted at 72 h and the SAB plates were counted on Day 5.

Statistics

Data were analysed with Statistical Package for the Social Sciences (SPSS) (Armonk, NY, USA) using a heteroscedastic, one-tailed *t*-test to compare how much the experimental sink cfu count deviated from the control sink cfu count.

Results

Control of microbial and fungal contaminates in sink traps by the experimental sink

Following the 4 days of incubation of the contaminated water in the p-traps of both the control and experimental sink (with decontamination mechanisms turned off), similar levels of cfu counts were observed in the p-traps of the experimental and control sinks. The active decontamination mechanisms were initiated for the experimental sink and 24 h later, there was a significant decrease in the number of cfu/mL in the experimental sink p-trap, whereas the control sink p-trap showed approximately a 2-log increase in the number of cfu/mL (Figure 2a). In this comparison of the microbial levels in the p-traps of control and experimental sinks, pooled results of three studies revealed significant differences that expanded over time. Overall, the number of bacteria (TSA plates) over the 11 days examined, decreased 95–100% in the experimental sink relative to the levels at initiation, while the cfu counts for the control sink remained high, and significantly increased compared to Day 1. Similar results were observed with the SAB plates to assess fungal contamination (Figure 2b) relative to

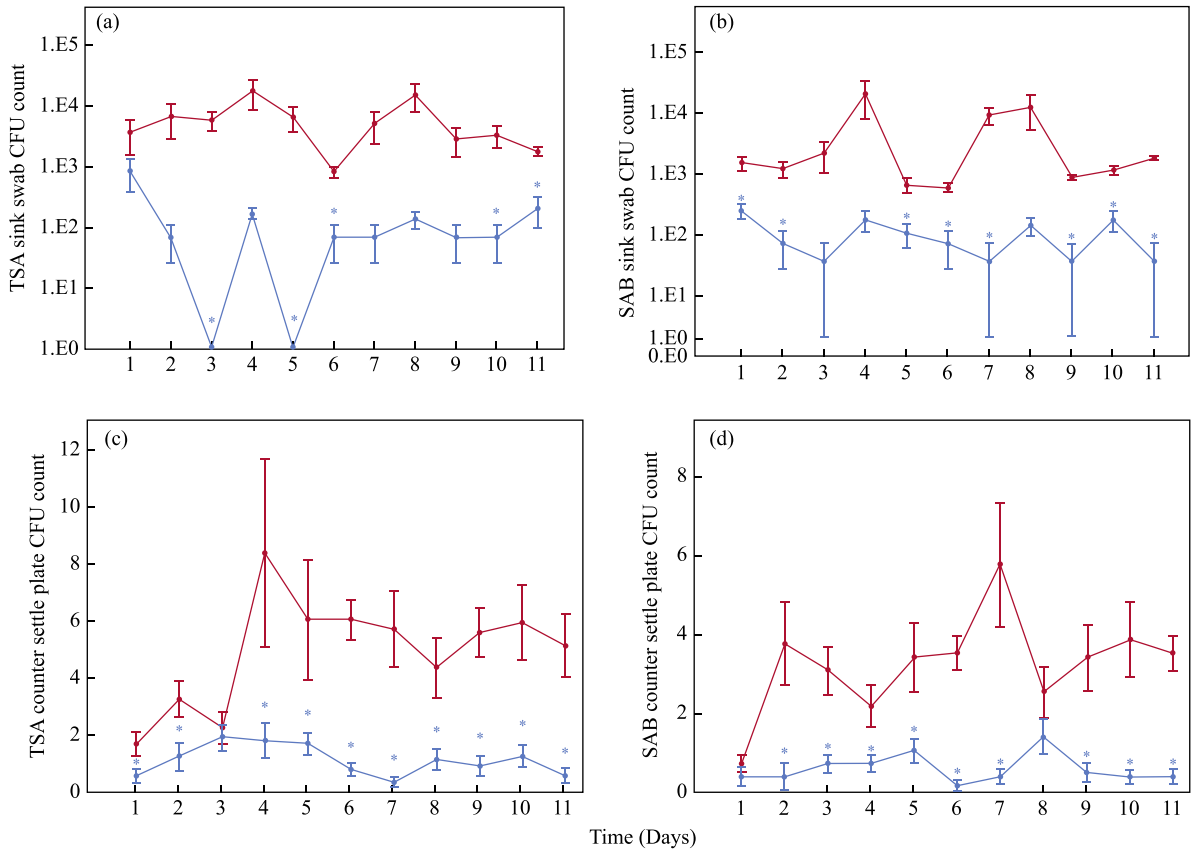

Figure 3. Pooled data (N=3) of sink swab and counter settle plate colony-forming unit (cfu) count on Tryptic Soy (TSA) and Sabouraud agar (SAB) for the control vs the experimental sink. (a) The cfu counts for TSA sink swab data for the control vs experimental sink, with the data statistically significant for Days 3, 5, 6, 10 and 11. (b) Shows the cfu counts for SAB sink swab data for the control vs experimental sink, with the data statistically significant (P<0.05) for Days 1–2, 5–7, and 9–11. (c) The cfu count for TSA settle plates placed on the counter of the control and experimental sink. Data was statistically significant (P<0.05) on Days 1–11. D Shows the cfu count for SAB settle plates placed on the counter of the control and experimental sink. When comparing the cfu count for the control vs the experimental sink, the data was statistically significant (P<0.05) on Days 2–7, and 9–11.

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the microbial plates. The results from both the TSA (Figure 2a) and SAB plates (Figure 2b) for the experimental sink decreased over time resulting in approximately 10 cfu/mL on Day 11, a significant decrease compared to the 10^7 bacteria/fungi per mL at the initiation of the study. In contrast, the control sink, following the increase in bacteria/fungi per ml on Day 2, maintained a steady number of cfu at approximately 10^9 bacteria or fungi per mL. The activity of the containment measures by the experimental sink appeared to be broad as varying sources for the starting inoculum were utilized.

These experiments were undertaken to include the addition of waste liquids that might be added to the sink in a hospital setting, to test the characteristics of the experimental sink. As shown with the pooled data (Figure 2) for the p-trap samples, the differences were significant for all days sampled (Days 1 through 11) for both the SAB and TSA plates when comparing the control sink vs the experimental sink. By Day 11, the cfu counts for the control vs experimental sinks were 441,500,000 ± 269,210,718 vs 17 ± 41 for SAB, and 471,333,333 ± 445,032,433 vs 17 ± 41 for TSA. Therefore, it is concluded that the experimental sink was capable of controlling the levels of microbial and fungal contamination in the p-trap.

Surface contamination on the counter and within the sink basin

The number of bacteria and fungi acquired by swabbing a 3-cm^2 area of the sink deck and spread on TSA and SAB agar plates, are shown in Figure 3a and 3b, respectively. At time zero, similar numbers of bacteria (TSA plates) were observed from the two sinks (Figure 3a). In contrast, there was a significantly lower number of fungi (SAB plates) as assessed by the sink swab data (Figure 3b), for the experimental sink vs the control sink. Similar decreases in the number of cfu were observed with the experimental sinks as compared to the control sinks for both bacteria (Figure 3a) and fungi (Figure 3b) thereafter. Significant differences were observed for the pooled data sink swabs for Days 3, 5, 6, 10, and 11 for TSA plates and Days 1, 2 and 5—11 for SAB plates, when comparing the control sink vs the experimental sink. For example, the cfu counts on Day 11 for the control vs experimental sink were 1733 ± 372 vs 33 ± 93 for SAB plates and 1700 ± 629 vs 200 ± 233 for TSA plates. Thus, the TSA plates and SAB plates, at most of the sampling times, revealed a significant decrease in the number of cfu. It is noted that the bacteria contamination appeared to be better controlled on the experimental sink as compared to the fungal contamination with a 76% decrease on Day 11 vs Day 1 for bacteria and 86% for fungi.

The sink decking can also be contaminated by aerosols from the p-trap, as well as by room air, a source that cannot be as well controlled as aerosols from the p-trap. Regardless, there was a trend for a decrease in cfu counts on settle plates during the incubation period for the experimental sink vs the control sink for both TSA and SAB agar plates. This may be attributed to the negative pressure system controlling splash-back aerosols that occur when the initial inoculum is poured into the trap, supporting the hypothesis that the experimental sink decreases the level of microbes released into the local environment, including aerosols.

In additional studies, shown in Figures 3c and d,4, the effect of atmosphere contamination by aerosolization was compared, using 4-h settle plates on both the deck and within the sink basin. The results from the sink deck, as shown in Figure 3c and d for TSA and SAB plates, respectively, revealing a consistent decrease in bacterial contamination at all time-points examined, relative to the control sink. The results observed with the sink basins (Figure 3c and d) were greater for microbial contamination, which peaked at approximately 25 cfu as compared to 8 cfu on the deck. This suggests that the contamination from the room atmosphere was greater than that observed from within the sink. Similar results were observed with the fungal SAB plates. Settle plate data, for all experiments, document on average a lower cfu count for the plates in the experimental sink vs the control sink, with little difference for the counter cfu. The pooled settle plate data for TSA and SAB plates (Figure 4a and b) show that the difference in settle plate cfu for the sink basin was statistically significant on Days 1—11 for SAB and Days 1, 2, and 4—11 for TSA plates. The cfu number for the counter settle plate data for TSA and SAB (Figure 3c and d) was statistically significant on Days 1—11 for TSA and Days 1, 2, 5, 6, 7 and 8—10 for SAB plates. Taken

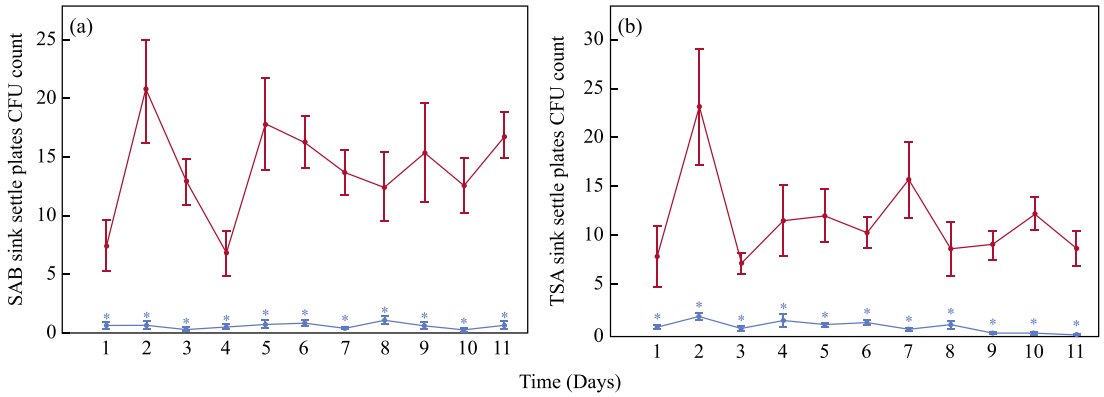

Figure 4. Pooled data (N=3) of sink settle plate colony-forming unit (cfu) counts on Tryptic Soy (TSA) and Sabouraud agar (SAB) for the control vs experimental sink. (a) The cfu count for SAB settle plates placed in the sink basin of the control and experimental sink. Data were statistically significant (P<.05) on Days 1—11. (b) The cfu count for TSA settle plates placed in the sink basin of the control and experimental sink. When comparing the cfu count for the control vs the experimental sink, the data was statistically significant (P<0.05) on Days 1—11.

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together, these results suggest that aerosolization from the p-trap, in addition to the room environmental contamination, may be significantly controlled by the parameters associated with this engineered sink, resulting in a significant diminution in room air contamination from the sink. It is noted that there is a two-to three-fold decrease in the bacteria on the experimental sink deck, as compared to the control sink, suggesting that this has the potential to limit the contamination of the room air.

Discussion

A number of studies has shown links between hospital room water systems and patient infections [33—35]. Indeed, in one 6-year study, removal of hand-washing sinks was shown to improve the control of an endemic multidrug-resistant Gram-negative bacteria infection [36]. Contaminated sinks have been implicated in several microbial outbreaks. Kramer and colleagues described that sinks can be hidden reservoirs generating large quantities of aerosols [31]. Starlander and co-workers noticed that four patients became infected or colonized by an extended-spectrum beta-lactamase (ESBL) -producing *Klebsiella pneumoniae* strain during a seven-month period on the neurological intensive care unit (ICU). Environmental sampling led to the conclusion that the plughole of the sink was the source of transmission [14].

Both the results in the literature [8,14,16,22—27,31,33,34] and in our studies show that the room sinks are a reservoir for (waterborne) bacteria and fungi to survive. Despite the efforts made in processes and disinfectants, multidrug-resistant bacteria continue to be found in p-traps and sinks from the flushing of fluids. These bacteria can colonize/infect patients and indeed, some patients show positive respiratory samples with those species found in sinks after a few days of hospitalization on the ICU [21,37]. Note that this study did not assess contamination following hand washing as this is challenging to standardize, and both sinks had automated and regular rinsing.

To our knowledge this is the first study to assess both aerosol and p-trap contamination longitudinally, comparing a self-disinfecting sink and trap to a standard sink. Further, this study documents that the sink basin and deck contamination are associated with aerosols from contaminated p-traps, and that self-disinfecting sink and drains can significantly control p-trap contamination and associated aerosols. Our study incorporated multiple negative controls in our analysis of both water and air contamination. However, our study did not type the pathogens and cannot prove a link between aerosols and p-trap contamination control and patient infections. Regardless, our results strongly encourage the installation of self-disinfecting sinks, such as the one discussed herein, to reduce hospital-acquired infections. Future studies are planned to compare aerosolization and contamination containment by standard vs self-disinfecting sinks in a clinical environment.

Conflict of interest statement

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