Microbial contamination of water sources for high-risk patients of a Pennsylvanian tertiary care facility

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Microbial contamination of water sources for high-risk patients of a Pennsylvanian tertiary care facility

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Abstract

The present study aims to investigate the extent of microbial contamination of hospital water sources in UPMC Mercy hospital, a Pennsylvanian tertiary care facility through environmental sampling and microbiological culturing. Following interpretation of results, assess the hospital’s use of mechanical filtration on unit floors and at distal points then provide recommendations for key stakeholders of the hospital so that actionable steps can be taken. Forty-five water samples were collected from the 8th floor general ICU, 4th floor trauma burn unit (TBU) ICU, 3rd floor medical surgical ICU, 4th floor unused ICU, 2nd floor endoscopy unit, and 5th floor hemodialysis unit. Water sources include filtered and unfiltered sources such as sinks, showers, hemodialysis boxes, nurses' water stations, and unit filtration systems. 35.6% (16/45) of water samples were positive for microbial growth as general ICU, medical-surgical ICU, and unused ICU were the main sources of the contamination. Patient sinks, showers, and hemodialysis boxes represent distal sites on the 8th floor general ICU that were contaminated even though the unit's double filtration system was negative for the water collected post filtration. In contrast, patient sinks and patient showers equipped with PALL filters on the 4th floor TBU ICU and hydrotherapy room showed no signs of microbial contamination. The results show that application of a double water filtration system on unit floors does reduce microbial contamination in the hospital water but has shown to not be effective in clearing microbial

contamination at distal sites of the water system. The preceding findings were presented to key stakeholders of the hospital resulting in infection preventionist led education for HCW staff on water flushing, a collaboration between engineers and hemodialysis unit to fit hemodialysis boxes with a hose connector to flush water, and whole genome sequencing of bacterial positive cultures. More research is needed to understand the extent of water-related HAIs to help create a comprehensive system that includes a water management program, preventative practices, and intervention strategies for water-related HAIs as they pose a substantial risk for patients in high risk settings.

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1.0 Introduction

Healthcare-associated infections (HAIs) are infections that are acquired while receiving health care and appear 48 or more hours following admission into a hospital (CDC, 2021a). HAIs persist as a significant contributor to patient morbidity and mortality resulting in the direct medical costs of more than $34 billion dollars each year to the U.S. hospital system (Scott et al., 2019). The hospital environment is a known reservoir for opportunistic pathogens with evidence of microbial contamination seen on high-touch patient surfaces, medical devices, and in hospital water systems (Facciolà et al., 2019; Hayward et al., 2020; Russotto et al., 2015). Unnoticed microbial contamination in the hospital environment leads to prolonged HAI acquisition among susceptible patients found in high-risk settings such as intensive care units (ICU) (Eyre et al., 2018; Weber et al., 2010). The responsibility to reduce the microbial burden is centered on the relationship between healthcare workers (HCWs) and infection preventionist (IP), fostered by excellent interpersonal communication. The IP is charged with routine surveillance of microorganisms in the environment and to provide education on best practices for nurses and clinicians as well as education on the employment of evidence-based disinfection practices (Chirca, 2019). The burden then largely falls on HCWs to be receptive and committed to the conceived system and in providing patient-centered care.

The role of high-touch patient surfaces and medical devices as a reservoir and in the transmission of opportunistic pathogens is well characterized but is not well understood for pathogens residing in the hospital water (Hayward et al., 2020). Hospital water pathogens can be responsible for direct transmission events or serve as a selective driver of antibiotic resistance in gram-negative organisms (Weinbren, 2020). In a summary of internal CDC records of HAIs between 2014 and 2017, researchers estimated 134 (21.6%) patient consultations involved water-related HAI events, implicating the substantial contribution of water-related HAIS to the overall growing problem of HAIs (Perkins et al., 2019).

1.1 Water source quality in tertiary care facilities

Commonly overlooked, hospital water distribution systems can be a potent source of opportunistic microorganisms in a hospital environment presenting a continual challenge for HCWs. Researchers frequently identified the opportunistic microorganisms as gram-negative bacterial species such as *Legionella spp.*, *Pseudomonas spp.*, and carbapenem-resistant *Enterobacteriaceae spp.* as well as gram-positive non-tuberculosis *Mycobacterium spp*. (D'Alessandro et al., 2015; Jamal et al., 2020; Millar & Moore, 2020; Montanari et al., 2009; Nakamura et al., 2020; Tang et al., 2020; Ziwa et al., 2019). All species represent opportunistic pathogens commonly seen in nosocomial environments.

Initially the municipal water supply that flows into the hospital water distribution system harbors opportunistic microorganisms as tertiary hospitals have shown that existent microbial contamination of the municipal water has led to persistent contamination of the hospital water distribution system when left untreated (D'Alessandro et al., 2015; Decker & Palmore, 2014; Vickers et al., 1987). Hospitals then use a process of chemical or mechanical treatment to reduce microbial water contamination (I Marchesi et al., 2020; I Marchesi et al., 2011).

Hospital water distribution systems can be contaminated in its proximal infrastructure being the central pipes supplying the water and at distal water outlets being point of use sites such as handwashing stations (Decker & Palmore, 2014). The water in the proximal infrastructure faces structural malignancies that create areas of stagnant water and differential heat, presenting ideal conditions for microbial growth of *Legionella spp.* and biofilm formation of *Pseudomonas spp*.(Chirca, 2019; Decker & Palmore, 2014). Resolving structural issues are costly and require administrative initiative but are feasible long-term solutions to microbiological contamination seen in the hospital water. The frequency of distal water outlets in a hospital presents a unique challenge in that its infrequent use or poor maintenance result in an opportunity for microbial colonization. Evidence of contamination is seen in patient sinks and showers that can go unused across different intensive care units (ICUs) as they are not necessary in the daily provision of care (Jamal et al., 2020; Montanari et al., 2009; Tang et al., 2020; Ziwa et al., 2019). Distal sites then serve as a risk for patient microbial colonization given their proximity to the patient and improper management. Other distal sites include nurse water stations and ice machines that have been colonized by non-tuberculous mycobacteria despite disinfective practices (Millar and Moore 2020). In the provision of care, water utilizing medical devices such as hemodialysis machines and hydrotherapy baths have been shown to be colonized by opportunistic pathogens in the dialysis filtrate and drains, respectively (Montanari et al., 2009; Tang et al., 2020; Ziwa et al., 2019). The significance of existent microbial contamination in the hospital water distribution system is the potential for patient colonization or infection through direct and indirect pathways offering multiple modes of transmission for the water pathogens.

1.2 Understanding patient risks to water related HAIs

1.2.1 Increased HAI acquisition for patients in high risk settings

In the past year, the CDC annual progress report revealed an increase in CLABSI, CAUTI, VAE, and MRSA bacteremia compared to 2019 (Monegro et al., 2021). The increasing incidence of HAIs challenges the current provision of care to susceptible patients seeking care in adult ICUs. Patient demographics established before admission to an ICU create an opportunity to estimate patient vulnerability to HAIs. Univariate risk factor analyses demonstrate that patient age, immunosuppression status, history of antibiotic use, diagnosis of cardiovascular disease, and diagnosis of diabetes mellitus implicate a higher risk of an HAI for patients (Despotovic et al., 2020; Rodríguez-Acelas et al., 2017). Following admission into an ICU, the care the patient receives can implicate higher risks for HAI acquisition being the duration of stay in the ICU, use of mechanical ventilation, intubation of central lines, and reoperation (Despotovic et al., 2020; Rodríguez-Acelas et al., 2017). Considering both pre and post admission risk factors for HAI acquisition in adult ICUs can help create a conceptual framework for understanding the risks that individual patients face.

1.2.2 Antibiotic resistance of water pathogens

The hospital environment is a driver of antimicrobial resistance with clinical practices of over-prescribing antibiotics and inadequate sanitation and infection control practices being the selective promoters (McEwen & Collignon, 2018). The sequelae is the increasing presence of antibiotic resistant organisms that complicate patient treatment regimens and lead to more severe outcomes during a patient infection. To combat antibiotic resistance, hospitals have adopted antimicrobial stewardship programs that demonstrated substantial benefits in clinical and economic outcomes in the past twenty years (Nathwani et al., 2019). The practices, although effective, exclude the presence of antibiotic resistant organisms in hospital water sources as a targetable intervention (Hayward et al., 2020).

A recent systematic review summarized water-associated HAI outbreaks in the U.S. in which researchers determined antibiotic resistant waterborne pathogens *P. aeruginosa, Mycobacterium spp., Legionella spp., S. aureus,* and carbapenem resistant Enterobacteriaceae (CRE) as the responsible agents (Hayward et al., 2020). Even with evidence of waterborne multidrug resistant organisms (MDROs), hospitals neglect the water sources in favor of supported antimicrobial stewardship programs. Theoretically, gram-negative pathogens can spread antibiotic resistance through mobile genetic elements in contaminated hospital water that could cause outbreaks of MDROs such as CRE. Interactions involving the spread of antibiotic resistance in hospital water sources are seen in the wastewater of healthcare facilities that show a significant number of antibiotic resistant water-borne pathogens in comparison to municipal water (Eda et al., 2021; Hassoun-Kheir et al., 2020). The interactions between the gram-negative bacteria could be a factor in increasing MDRO spread but there is no literature to support this.

1.2.3 Water associated outbreaks in tertiary care facilities

Gram-negative bacteria in water are associated with multiple reported infections in high risk patient settings of tertiary care facilities. Patient infections commonly occur in clusters from aerosol transmission from the water source, water splash events, exposure of implanted devices to water such as central venous catheters, contaminated water in medical devices, and from

HCW hands (Decker & Palmore, 2014; Vincenti et al., 2014; Yassin et al., 2020). At the National Institute of Health (NIH) there were multiple cases of *Sphingomonas* bacteremia and sepsis related to faucet water splash and contamination of medical and surgical equipment in an interdisciplinary ICU (Johnson et al., 2018). Investigators were only able to establish a genetic similarity between the hospital water reservoir of *Sphingomonas* and clinical isolates of *Sphingomonas* (Johnson et al., 2018). Continual transmission from water source to patient occurs and was seen in a German interdisciplinary ICU in which prolonged infections with multidrug resistant *P.aeruginosa* was the result of HCWs emptying ultra-filtrate bags used during hemofiltration in patient sinks leading to person to person transmission (Salm et al., 2016). There are numerous cases of bacteremia, endocarditis, and sepsis related to waterborne pathogens that follow the contamination of wounds, injection drug use, and contamination of dialysis access with faucet water (CDC, 1998; Chotikanatis et al., 2011).

Biofilm forming water pathogens are known to cause outbreaks or "pseudo-outbreaks" in dialysis centers and in patient ventilators or heart lung machines (Montanari et al., 2009). The formation of the biofilm leads to persistent colonization of pathogens that are difficult to treat, often requiring replacement of the biofilm contaminated source (Donlan & Costerton, 2002). In a Pittsburgh tertiary care facility there is an ongoing, large pseudo-outbreak of *Delftia acidovorans* associated with biofilm contamination of the reverse osmosis water in the hemodialysis machines (Yassin et al., 2020). *D. acidovorans* is a waterborne pathogen residing in the Pittsburgh municipal water and can infect susceptible patients directly. *P.aeruginosa, another* opportunistic pathogen known for its biofilm formation, was also found in the reverse osmosis water of hemodialysis machines at a different tertiary care facility, exhibiting high resistance rates to antibiotics (Vincenti et al., 2014). Both investigations into the pseudo-outbreaks recognized the replacement of the reverse osmosis filters and hemodialysis machines as the cost-effective method for eliminating the contamination (Vincenti et al., 2014; Yassin et al., 2020).

The outbreaks highlight that microbial contamination of the hospital water system in its proximal or distal infrastructure can lead to patient infections directly or indirectly in adult ICUs. Current practices in patient treatment that involve an exposure to contaminated water may result in a water-related outbreak that necessitates an immediate intervention for the patient and causative source.

1.3 Current standards for hospital water management

The Joint Commission and CDC oversee water management programs across the U.S. hospital system. The CDC provides guidelines in the form of toolkits to create water management programs in which The Joint Commission sets and enforces standards for hospitals and water management programs (CDC, 2021b; The Joint Commission, 2021b). A new standard issued by The Joint Commission, Standard EC 02.05.02 goes into effect January 1st, 2022 and requires hospitals, critical care facilities, and nursing care centers to create a water management program that addresses *Legionella* and other water pathogens (The Joint Commission, 2021a).

The main purpose of the new standards is to protect patient and HCW health using a systems approach to water treatment. Previous standards were broad and lack specific guidance on targeted water treatment strategies, creating variation in water treatment strategies in U.S. hospitals with different tertiary care facilities exploring novel solutions for microbiological contamination within their hospital water distribution systems (CDC, 2021b; The Joint Commission, 2021a). Currently tertiary care facilities flush distal outlets for at least 5 minutes at

65℃ called superheating to decontaminate sites with *L. pneumophila*, but this straightforward strategy has proven ineffective in eliminating long-term contamination (Chen et al., 2005). Longitudinal studies of different control strategies for *L. pneumophila* in tertiary care facilities identified hyperchlorination (>10mg/L of free chlorine at point of delivery), the use of electric boilers, and point of use filters as the cheapest, most-effective strategies for reducing systemic contamination of *L. pneumophila* in the hospital water system (Isabella Marchesi et al., 2020; I Marchesi et al., 2011). Although only applied to *L. pneuomophila*, these water treatment strategies can reduce the microbial burden of other pertinent bacterial species.

UPMC Mercy, a tertiary care facility in Pittsburgh, Pennsylvania uses a two-pronged approach of systemic chemical treatment and mechanical filtration to reduce the microbial burden in the hospital water distribution system. The water flowing through the proximal infrastructure is treated with monochloramine, successfully eradicating *Legionella* from their water system (Kandiah et al., 2013). High-risk patient settings including the general ICU, trauma burn ICU, hydrotherapy rooms, and hemodialysis units have a double filtration system on the floor to supply filtered water into distal sites. Theoretically, the double filtration system works to further reduce the microbial burden of patient accessible water. The trauma burn ICU equipped all patient sink and shower heads with PALL filters to prevent continued colonization at distal water sites (Loveday et al., 2014). Oversight of the water distribution system involves IP, nurses, and cleaning staff in maintaining distal water sources through environmental rounding or employing point of use guidance such as letting patient showers run before use. Even with the establishment of a complex water management program, evidence of microbiological contamination of hospital water continues to emerge within the hospital.

1.4 Specific aims

1. Describe the extent of positive water cultures in high-risk patient environments at a tertiary care hospital through environmental sampling and microbiological culturing

2. Assess the hospital’s use of mechanical filtration on unit floors and at distal points.

3. Provide recommendations and implication for the key stakeholders and hospital to take actionable steps

2.0 Methods

2.1 Research approach

The cross-sectional study was conducted using environmental water samples collected during the month of October 2021in a tertiary care hospital in Pittsburgh, Pennsylvania. Forty-five water samples were collected from filtered and unfiltered water sources in the hospital. The sample distribution is as follows: nineteen samples from 8th floor general ICU, seven samples from 4th floor trauma burn unit (TBU) ICU, four samples from 4th floor unused ICU, four samples from the 2nd floor endoscopy unit, seven samples from the 3rd floor medical surgical ICU, and four samples from the 5th floor hemodialysis unit.

The maintenance team collected environmental water samples from the hemodialysis unit and floor unit water filtration systems. The distribution of collected water sources and origins is outlined in **Table 1**.

Table 1 Sample collection schema for hospital water samples

Patient Unit	Sample Source	Samples Collected	Collective Total
General ICU 8th Floor			19
Sinks	Patient Room	5	
Showers	Patient Room	5	
Hemodialysis Boxes	Patient Room	5	
Hemodialysis Pre-Post Filter	Floor Unit	4	
TBU ICU 4th Floor			26
Sinks	Patient Room	3	
Nurse water station	Floor Unit	2	
Pre-Post filter hydrotherapy room	Floor Unit	2	
MS ICU 3rd Floor			33
Sinks	Patient Room	4	
Nurse water station	Floor Unit	2	
Nurse sink	Floor Unit	1	
Endoscopy Unit 2nd Floor			37
Sinks	Patient Room	4	
Unused General ICU 4th Floor			41
Sinks	Patient Room	4	
Hemodialysis Unit 5th Floor			45
Hemodialysis Sink	Floor Unit	1	
Hemodialysis Unit	Floor Unit	1	
Hemodialysis Pre-Post Filter	Floor Unit	2	

2.2 Sample collection

Water was collected from unit sinks, showers, nurse water stations, hemodialysis boxes, and unit filtration systems. The water was allowed to run for 10 seconds, and then 100mL of water was collected into sterile 100mL collection tubes. The water was stored at 37℃ and within 48 hours samples were cultured.

2.3 Microbiological culturing and analysis

100mL of the water sample was vacuum filtered using 0.2-micron Nalgene membranes. The Nalgene membrane was then aseptically transferred to a TSA plate using sterile tweezers. TSA plates were incubated at 36℃ for 72 hours. Following incubation, results of bacterial growth were determined and recorded. Positive bacterial growth was recorded as <10 colonies, 10 to 100 colonies, and too numerous to count (TNTC).

All positive TSA cultures were subsequently cultured on MacConkey agar and Blood agar plates. Single colonies from positive TSA cultures were picked and streaked onto MacConkey and Blood Agar plates. MacConkey and Blood agar plates were incubated at 36℃ for 48 hours. Following incubation, results of bacterial growth were determined and recorded. Positive cultures represent bacteria that show countable growth on TSA and Blood agar plates.

3.0 Results

3.1 Extent of positive water cultures in UPMC Mercy

Table 1 displays the distribution of forty-five environmental water samples collected at distal and proximal sites of the UPMC Mercy water distribution system (**Table 1**).

Table 2 Distribution and frequency of positive water cultures across ICU units and hospital

Unit Type	Positive Samples (%)
ICU Units	16/37 (41.7)
Sinks and showers	13/22 (59.1)
Hemodialysis Boxes	5/5 (100)
Nurse water stations	2/4 (50)
Unit pre-post filters	1/6 (16.7)
Endoscopy Unit 2nd Floor	
Sinks	0/4 (0)
Hemodialysis Unit	
Sink	0/1 (0)
Units	0/3 (0)
Filtered vs. Unfiltered water	16/45 (35.6)
Filtered	8/31 (25.8)
Unfiltered	8/14 (57.1)

The results show that 35.6% (16/45) of the water samples were positive for microbial growth (**Table 2).** Distal sites in the 8th floor general ICU and 3rd floor medical surgical ICU represent the main source of microbial contamination of the sampled water sources being that 59.1% of sinks and showers, 100% of hemodialysis boxes, and both the ice and water of the nurse water station were positive for microbial growth (**Table 2).** Proximal sites of the adult ICUs include the unit double filtration systems located on the 8th floor general ICU and 4th floor TBU ICU. Both filtration units showed no evidence of microbial contamination in the filtered water although the pre-filtered water collected from the 8th floor general ICU filtration system was positive for microbial growth. ICU units that do not have a unit filtration system include the 3rd floor medical-surgical ICU and the 4th floor unused ICU. In comparison of filtered and unfiltered sources of water, 25.8% of filtered water sources were contaminated and 57.1% of unfiltered water sources were contaminated (**Table 2)**.

4.0 Discussion

The present study shows evidence for microbial contamination within the hospital water system in high-risk patient settings. In comparison of filtered and unfiltered water sources, 25.8% (8/31) of filtered and 57.1% (8/14) of unfiltered water sources were contaminated. The main sources of microbial contamination of filtered water sources are seen at distal sites of the 8th floor general ICU as 61.5% (8/13) of sinks, showers, and hemodialysis boxes sampled from patient rooms were positive for microbial growth. The proximal infrastructure of the water system being the 8th floor double filtration system shows evidence of contamination prior to being filtered but the water collected post filtration was negative for microbial contamination.

The unexplained distal contamination seen on the 8th floor general ICU can potentially be attributed to the local water distribution system on the floor that supplies the water from the double filtration system to the patient rooms. PALL filters used in patient sinks and showers as well as the hydrotherapy room on the 3rd floor TBU ICU showed no signs of microbial contamination, demonstrating their effectiveness as a point of use filtration system in comparison to unit filtration systems. 80% (8/10) of patient sinks on the 3rd floor medical-surgical ICU and the 4th floor unused ICU were contaminated. Both units do not have a double filtration system so there was an expectation of microbial contamination, given these are unfiltered water sources. Additionally, the nurses' water station of the 3rd floor medical-surgical ICU was contaminated in both the water and ice it provided that might need to be replaced if standard disinfection practices do work.

The application of a double water filtration system on unit floors does reduce microbial contamination in the hospital water but has shown to not be effective in clearing microbial contamination at distal sites of the water system. Particularly, the 8th floor general ICU and 3rd floor medical-surgical ICU shows evidence of widespread contamination of patient accessible water sources implicating a higher risk for patient transmissible events. Although no direct transmission events were observed in both units, those water sources serve as potential outbreaks for the ICU units as this is seen in the extended outbreak *K. oxytoca* in a medical-surgical ICU in which outbreak associated clones of *K. oxytoca* were ubiquitous in patient sinks of the ICU (Lowe et al., 2012).

The preceding findings and conclusions were presented to relevant stakeholders at UPMC Mercy including the director of critical care, the lead engineer, infectious disease clinicians and IPs. The discussion resulted in actionable steps that are as follows. The IP personnel will provide education to nursing staff located on the 8th floor general ICU to routinely flush and flush the water before use for all distal water sources located in patient rooms. The hemodialysis boxes within patient rooms are locked and given that they are meant to connect to a direct water line there's no way to flush the water without flooding the patient room. To address this, the hemodialysis unit and engineers will work to unlock all hemodialysis boxes and to fit each unit with a hose connector that allows the water to be easily flushed and accessible to the nursing staff. Lastly, the water samples that were successfully cultured will be sent to Phigenics, an independent water management company, to be sequenced using whole genome sequencing to identify the microorganisms present in the UPMC Mercy water.

General limitations of the study involve the research approach being that sample size was small. Collecting more water samples from unit floors, particularly the 8th floor general ICU and 3rd floor medical-surgical ICU, would paint a more accurate picture of the distribution and frequency of microbial contamination of hospital water. During sample collection, water was only flushed for ten seconds prior to being collected, which does not adhere to the actual practice of water flushing that can last more than a minute. At the time of collection this seemed impractical, as collecting water from hemodialysis boxes would cause flooding of the patient room if it was flushed for more than ten seconds so to maintain consistency, all water sources were flushed for ten seconds. The simple error in approach could contribute to the high positivity of water cultures collected from patient showers and hemodialysis boxes on the 8th floor general ICU as these water sources could have gone unused for weeks, in which there could be a buildup of microbial contamination that needs to be flushed.

5.0 Conclusion and recommendations

The central limitation of the study is that it cannot address, if microbial contamination at distal water sites in high-risk patient settings be identified as a targetable intervention? Simply proposing there is microbial contamination at distal water sites can lead to costly and time-consuming interventions that result in no clear benefit to the patient. Instead, determining that there is persistent microbial contamination of the water source within the patient unit would be sufficient rationale for an intervention to prevent patient colonization and infections. Targeted interventions can be used such as the employment of point of use filters at distal water sites, which is a proven effective measure to reduce endemic infections and colonization of patients in high-risk settings (Cervia et al., 2010; Trautmann et al., 2008).

If continued microbial colonization is seen in patient water sources on the 8th floor general ICU and 3rd floor medical surgical ICU, PALL filters should be considered as a final means of eliminating microbial contamination without having to replace the distal infrastructure. Overall more research is needed to understand the extent of water-related HAIs to help create a comprehensive system that includes a water management program, preventative practices, and intervention strategies for water-related HAIs as they pose a substantial risk for patients in high risk settings.

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