Efficacy and Effectiveness of Showerheads Attached with Point-of-use (POU) Filter Capsules in Preventing Waterborne Diseases in a Japanese Hospital

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Received 22 May, 2020/Accepted 22 July, 2020

Tap water contamination is a growing concern in healthcare facilities, and despite chlorination, tap water in these facilities contains several pathogenic microorganisms causing healthcare-associated waterborne infections or nosocomial outbreaks. Shower units are particularly prone to contamination as they are conducive for bacterial growth and can even produce bioaerosols containing pathogenic bacteria. Shower units coupled with point-of-use (POU) water filters are a simple and safe option; however, their efficacy has been under-reported. Therefore, we determined the efficacy of showerheads attached with a POU filter capsule in preventing infections in our hospital. We investigated the presence of pathogenic bacteria in water sampled from three shower units. After replacing the original shower units with new ones incorporated with a sterile-grade water filter capsule (0.2 µm; QPoint™), the water samples were analyzed for up to 2 months. The POU filters removed several pathogenic bacteria (Mycobacterium, Pseudomonas, Stenotrophomonas, Aeromonas, and Klebsiella spp.). Filter effectiveness depends on regional water quality and we believe that effective tap water treatment combined with the use of POU filters (introduced at a reasonable cost in healthcare facilities) can considerably minimize waterborne diseases in hospitals and improve patient care.

Key words: Hospital water hygiene / Shower head / Point-of-use (POU) filter / Bacterial contamination / Legionella spp.

INTRODUCTION

Contamination of tap water in healthcare facilities is an important issue associated with infection control (Decker et al., 2013). Although tap water contains chlorine as a disinfectant according to the statute of the healthcare facilities, a wide variety of aquatic microorganisms can contaminate tap water (Vaz-Moreira et al., 2017). Some of these microorganisms such as Legionella pneumophila (Franzin et al., 2004, Lowry et al., 1993, Oren et al., 2002), Pseudomonas spp. (Fujitani et al., 2011, Safiri et al., 2017), and nontuberculous Mycobacterium spp. (Baker et al., 2017, Conger et al., 2004) can cause life-threatening diseases, healthcare-associated waterborne infections, or nosocomial outbreaks in humans. Therefore, infection control staff need to continue their efforts in reducing the bacterial contamination of tap water in their healthcare facilities.

Although all water supplies have a risk of bacterial...
contamination, the shower unit is particularly prone to contamination. Shower units are conducive for bacterial growth and biofilm formation (polyvinyl chloride resin material, low flow rate, and water temperature range of 25–45°C). In addition, showers can produce bioaerosols that contain pulmonary infection-causing bacteria (Estrada-Perez et al., 2018, Thomson et al., 2013). Thus, bacterial contamination due to shower units in healthcare facilities deserves special attention.

Traditional methods such as water heating (60–65°C for 30 min) or using antimicrobial chemicals (monochloramine, chlorine dioxide, or hydrogen peroxide) have been used to prevent bacterial contamination of water systems (Borella et al., 2016, Casini et al., 2017). However, these procedures require considerable effort for maintaining the effective conditions and are disadvantageous as they consume high energy and post the risk of scalding or chemical toxicity. Copper and silver ionization is also an easy option but this method requires continuous monitoring of copper and silver ions (Cachafeiro et al., 2007).

In contrast, point-of-use (POU) water filters (0.2-µm pore size) are a simple and safe method for preventing nosocomial infections due to Legionella spp. and Pseudomonas spp., particularly in high-risk areas (Borella et al., 2016, Trautmann et al., 2008). However, POU filtration units may be biologically contaminated during use and can promote the occurrence of nosocomial infections (Götting et al., 2019), and this issue has not been adequately studied in an actual clinical setting. In addition, although the efficiency of POU filters may differ depending on regional water quality, little has been reported on their efficacy in Japanese hospitals.

In 2017, we encountered a case of nosocomial Legionella pneumophila pneumonia caused by a contaminated shower unit in our hospital. Environmental investigation showed that many shower units of our hospitals had been contaminated with Legionella spp. We replaced the contaminated shower units with new ones as an infection control measure. Thereafter, showerheads attached with 0.2 µm sterile-grade water filter capsules (QPoint™; Pall Corporation; 88 mm in diameter, 40 mm in thickness) (FIG. 1). Then, we again collected water samples as described above. We also collected water samples from these three shower units for one and two months (the end of an operation guarantee period set by the maker) after showerhead replacement.

Analyzing bacterial contamination of shower units:
The water samples from the shower units were filtered through membrane filters with a diameter of 47 mm and a pore size of 0.45 µm (Pall Corporation). The water samples obtained using original showerheads for evaluating contamination due to common pathogenic bacteria were diluted 10-fold with sterile saline and the diluents (100 mL) were filtered through the membrane filters. The water samples (100 mL) obtained using new showerheads were directly filtered through the membrane filters. The filters for counting common pathogenic bacteria were then placed on plates containing sheep blood agar (Nissui Pharmaceutical, Co., Ltd, Tokyo, Japan.) and after incubation at 37°C for 24 h, the colonies were counted. The water samples (100 mL) for evaluating contamination due to gram-negative bacteria were directly filtered through the membrane filters. The filters for counting gram-negative bacteria were then placed on plates containing deoxycholate hydrogen sulfide lactose (DHL) agar (Nissui), and the colonies were counted after incubation at 37°C for 24 h. Furthermore, the growing colonies on the DHL plates were identified by Matrix-Assisted Laser Desorption Ionization-Time of Flight Mass Spectrometry (MALDI TOF MS) (Bruker Daltonics, Bremen, Germany). On the other hand, the filters for counting Legionella spp. were then placed on the plates containing Wadowsky-Yee-Okuda (WYO-α) agar (Eiken Chemical Co., Ltd, Tokyo, Japan), and the colonies were counted after incubation at 37°C for 72–168 h. Furthermore, the growing white colonies on the WYO-α plates were also identified by MALDI TOF MS.

MATERIALS AND METHODS

Water sampling for analyzing bacterial contamination of shower units:
Three shower units (A, B, and C) in three private patient rooms that had been actually used by patients were used in this study. All the three shower units had commercially available popular showerheads. Water samples (100 mL) in the range of common operating temperature (36–40°C) were collected in sterile bottles (Eiken Co., Ltd, Tokyo, Japan.) after flushing the water for 1 min for counting common bacterial colonies. For counting gram-negative bacterial colonies, 100 mL samples were collected in a sterile bottle (Eiken). For counting the colonies for Legionella spp., 1,000 mL water samples were collected in a sterile bottle (Sanplatec Co., Ltd., Osaka, Japan.) containing sodium thiosulfate at standard concentrations.

After water sampling was performed, the original showerheads were replaced with new showerheads attached with 0.2 µm sterile-grade water filter capsules (QPoint™; Pall Corporation; 88 mm in diameter, 40 mm in thickness) (FIG. 1). Then, we again collected water samples as described above. We also collected water samples from these three shower units for one and two months (the end of an operation guarantee period set by the maker) after showerhead replacement.
Measuring the volume of water flow:
The water pressure will affect the satisfaction of a user utilizing a shower. Therefore, we measured the volume of water flowing through the original and new showerheads attached with 0.2-µm sterilizing-grade filter capsules to evaluate the water pressure from showerheads.

Silt density index (SDI) test:
The silt density index (SDI) test is a popular method for determining feed water quality. We attached the SDI test kit (Pall Corporation) at the end of the shower hose after removing the showerhead. Then, we attached the certified 0.45-µm membrane (Pall Corporation) to the test kit after flushing water for 1 min. The water was made to flow in the test kit for 15 min. Then, we measured the time required for 500 mL of water to flow into the kit at commencement of water flow (t₀) and 15 min after commencement (t₁₅). SDI was determined according to the following formula, wherein 15 was substituted for Tf (ASTM International, 2014, Hosseinzadeh et al., 2013).

\[
SDI = \left( \frac{1 - \frac{t_{15}}{t_0}}{T_f} \right) \times 100
\]

Measuring hydrostatic pressure:
We attached the pressure gauge (Nagano Keiki, Co., Ltd., Tokyo, Japan) to the end of the shower hose after removing the showerhead. Then, we measured the hydrostatic pressure by fully opening the valves.

Experimental model verification:
We also evaluated the bacteria-filtering effect of the showerheads attached with POU water filter capsules using the experimental shower unit model and three bacterial strains as test microorganisms. *Brevundimonas diminuta* ATCC 19146, which is a small gram-negative bacterium, was used for validating membranes and filters. The other two microorganisms used were the highly pathogenic *Klebsiella pneumoniae* BWH2 (NR-41897) and *P. aeruginosa* ATCC 10145. Frozen pellets of *B. diminuta* were suspended in sterile saline for adjusting to concentrations of approximately 100–1,000 CFU/mL. The actual concentration of *B. diminuta* cells was measured before use. *K. pneumoniae* and *P. aeruginosa* were inoculated on sheep blood agar (Nissui) plates that were then incubated at 37°C for 24 h. Thereafter, the bacterial cells were harvested from the plates and suspended in sterile saline for adjusting to concentrations of approximately 100–1,000 CFU/mL. The actual concentrations of *K. pneumoniae* and *P. aeruginosa* cells were also measured before use. Common showerheads (commercial products) with polyvinyl chloride shower hoses that were sterilized using ethylene oxide gas were attached to the stainless steel pressure vessels (Union Controls Co., Ltd., Chiba, Japan.) filled with 5 L of each suspension (*B. diminuta, K. pneumoniae, P. aeruginosa*). Thereafter, 5 L of each suspension was injected into each shower hoses under the confining pressure of 1 kgf/cm² using a pressure

![FIG. 1. Showerhead incorporated with the POU filter capsule (QPoint™). (a) The showerhead attached with POU filter capsule (arrow). (b) The showerhead holder with the removed POU filter capsule (arrow). This capsule is easily attached to and detached from the showerhead holder.](image)
regulator (Pall Corporation). Thereafter, water samples (5 L) from each showerhead were collected in a sterile tank.

The water samples were diluted $10^3$, $10^4$, and $10^5$-fold with sterile saline, and each diluent (100 mL) was filtered through membrane filters with a diameter of 47 mm and a pore size of 0.2 µm (Pall Corporation). The filters for counting test microorganisms were then placed on Soybean Casein Digest (SCD) Agar plates (Kohjin Bio Co., Ltd, Saitama, Japan). And after incubation at 32°C for 48 h, the colonies of *B. diminuta* were counted. The plates were incubated at 37°C for 12 h, and then the numbers of colonies on the plates were counted for *K. pneumoniae* and *P. aeruginosa*.

Thereafter, water samples were similarly collected using new showerheads attached with 0.2-µm sterile-grade water filter capsules (QPoint™; Pall Corporation) as described above. The water samples (1 L) from new showerheads were directly filtered through the membrane filters and after incubation at 32°C for 48 h (for *B. diminuta*) or 37°C for 12 h (for *K. pneumoniae* and *P. aeruginosa*), the colonies were counted.

**RESULTS**

As summarized in TABLE 1, around 400 CFU/100 mL of common pathogenic bacteria were detected in the water samples obtained using original showerheads. Typical major colonies identified were *Brevundimonas* spp., *Mycobacterium* spp., *Bacillus* spp., or *Sphingomonas* spp. In shower units A and C, gram-negative bacteria were not detected in the water samples obtained using the original showerheads. However, the water samples obtained using the original showerheads in shower unit B contained uncountable gram-negative bacteria. Typical major colonies identified were *Pseudomonas* spp., *Stenotrophomonas* spp. or *Aeromonas* spp. and some colonies were identified as *Klebsiella* spp. *Pseudomonas* spp. were predominantly found in which samples. We could not detect *Legionella* spp. in the samples obtained by using the original showerheads.

We detected one colony of *Staphylococcus epidermidis* in 100 mL of the water sample obtained from the new showerhead attached with the filter capsule immediately after showerhead replacement in shower unit A. In shower unit C, two colonies of *S. capitis* were detected in a 100 mL water sample obtained using the new showerhead two months after showerhead replacement. No other bacteria including gram-negative bacteria or *Legionella* spp. were detected in any sample obtained using the new showerheads at any sampling time except for the above in all the three shower units.

In shower unit B, the volume of water flowing through the new showerhead was almost the same as that through the original showerhead. However, in shower units A and C, the volume of water was relatively less obtained using the new showerheads than that obtained using the original showerheads. In addition, the flow of water in shower units A and C containing the new showerheads was relatively less compared to the flow of water in the same shower units containing the original showerheads. In this study, the hydrostatic pressure was within the range of 81–155 KPa. SDI was within the range of 0.6–3.23.

Results of experimental model verification are summarized in TABLE 2. Approximately 400 CFU/mL of all the three test organisms were detected in the water samples obtained using the common showerheads. However, the test microorganisms were not detected at all in the water samples obtained using the new showerheads attached with the filter capsule.

**DISCUSSION**

Tap water is used for various purposes in healthcare facilities although that contains opportunistic premise plumbing pathogens such as *L. pneumophila*, nontuberculous *Mycobacterium* spp., *Pseudomonas* spp., *Acinetobacter* spp., *Stenotrophomonas maltophilia*, and *Burkholderia cepacia* (Falkinham et al., 2015, Parkinson et al., 2020). Recently, water hygiene in healthcare facilities is being advocated and is attracting considerable attention because these bacteria can cause healthcare-related infections and outbreaks (Conger et al., 2004, Decker et al., 2013, Franzin et al., 2004, Reynolds et al., 2008, Safiri et al., 2017). Especially, immunocompromised patients including the patients in burn units, hematology-oncology units, transplant units, and intensive care units (ICUs)/neonatal ICUs need safer water.

Shower units are prone to bacterial contamination because they are conducive for bacterial growth and biofilm formation. Contaminated shower units can produce bioaerosol-containing pathogenic bacteria that can cause pulmonary infections especially in immunocompromised patients (Estra-da-Perez et al., 2018, Thomson et al., 2013). Hence, bacterial contamination of shower units in healthcare facilities should not be ignored.

POU water filters may be an appropriate option that can help in providing clean water in medical facilities (Parkinson et al., 2020). They have been used since decades for supplying safe drinking water in areas with no access to clean water, such as developing countries (Wolf et al., 2018). However, their usefulness is not limited to developing countries. The effectiveness of POU filters for drinking water has been studied with immense interest even in USA (Reynolds et al., 2008).
| Shower unit | Measurement items | Original showerhead | After removing the original showerhead | After removing the new showerhead |
|-------------|-------------------|---------------------|----------------------------------------|----------------------------------|
|             | Total viable bacterial count | 410 | 1\(^{(*)3}\) | 0 | 0 |
|             | (CFU/100 mL) | | | | |
|             | Common pathogenic bacteria | | | | |
|             | (CFU/100 mL) | | | | |
|             | Gram-negative bacteria | 0 | 0 | 0 | 0 |
|             | (CFU/100 mL) | | | | |
|             | Legionella spp. | 0 | 0 | 0 | 0 |
|             | (CFU/1000 mL) | | | | |
| A           | Water temperature (°C) | 36.6 | NA | NA | 39.8 |
|             | Water flowing (L/min) | 4.8 | 3.9 | 3.2 | 3.0 |
|             | Hydrostatic pressure (kPa) | 81-115 | | | 95 |
| B           | Total viable bacterial count | 430 | 0 | 0 | 0 |
|             | (CFU/100 mL) | | | | |
|             | Common pathogenic bacteria | | | | |
|             | (CFU/100 mL) | | | | |
|             | Gram-negative bacteria | Uncountable | 0 | 0 | 0 |
|             | (CFU/100 mL) | | | | |
|             | Legionella spp. | 0 | 0 | 0 | 0 |
|             | (CFU/1000 mL) | | | | |
| A           | Water temperature (°C) | 39.5 | NA | NA | 39.3 |
|             | Water flow (L/min) | 5.7 | 5.7 | 6.8 | 7.5 |
|             | Hydrostatic pressure (kPa) | 123 | | | 137 |
| C           | Total viable bacterial count | 370 | 0 | NA | 2\(^{(4)}\) |
|             | (CFU/100 mL) | | | | |
|             | Common pathogenic bacteria | | | | |
|             | (CFU/100 mL) | | | | |
|             | Gram-negative bacteria | 0 | 0 | NA | 0 |
|             | (CFU/100 mL) | | | | |
|             | Legionella spp. | 0 | 0 | NA | 0 |
|             | (CFU/1000 mL) | | | | |
| A           | Water temperature (°C) | 39.3 | NA | NA | 39.4 |
|             | Water flow (L/min) | 13.6 | 8.7 | NA | 7.6 |
|             | Hydrostatic pressure (kPa) | 155 | | | NA |

\(^1\): Colonies on sheep blood agar plates were defined as Common pathogenic bacteria, 
\(^2\): Colonies on DHL agar plates were defined as Gram-negative bacteria, 
\(^3\): Staphylococcus epidermidis, \(^4\): Staphylococcus capitis.
In medical facilities, POU filters are also useful for filtering out aquatic microorganisms (Baron et al., 2014, Lin et al. 2011, Zhou et al. 2014). Especially, although waterborne Legionella and Mycobacterium spp. are difficult to eliminate from systems providing water for daily consumption, POU filters can effectively filter them out (Marchesi et al., 2011).

Thus, introducing POU filters in clinical settings could be immensely valuable in infection control. In fact, several studies have reported the effectiveness of these filters in reducing healthcare-related infections due to aquatic bacteria in recent years. For example, Barna et al. (2014) reported that the incidence of nosocomial P. aeruginosa infections decreased from 2.71 to 0 cases/100 patient-days when the filters were used at their ICU. Zhou et al. (2014) reported that colonization/ infection due to gram-negative bacteria determined using patient clinical specimens was reduced by 47% after the installation of POU water filters. Cervia et al. (2010) reported that clinical infection rates in their bone marrow transplant unit were significantly reduced from 1.4 in total and 0.4 gram-negative bacterial infections per 100 patient-days in the period before POU filtration to 0.18 in total and 0.09 infections per 100 patient-days in the 9-month period during which filters were installed. In our study, the POU filters removed a considerable number of bacteria including pathogenic bacteria such as Mycobacterium, Pseudomonas, Stenotrophomonas, Aeromonas, and Klebsiella spp. Unfortunately, the effect of removing Legionella spp. could not be evaluated in this study because Legionella spp. had been completely removed by infection control countermeasures undertaken before this study. The effect of bacterial removal continued for two months in accordance with the effectiveness guarantee period set by the filter manufacturer. Moreover, in our experimental verification test, POU filters were able to remove bacteria at a concentration ranging from 100 to 1,000 CFU/mL, suggesting that POU filters are effective even for a higher level of bacterial contamination of shower units than that found in our hospital.

However, POU filters have certain limitations. For example, POU filtration units may be biologically retrograde contaminated during use by back-splashing water and contaminated aerosols, and it can thus be the source of nosocomial infections (Götting T et al., 2019). In our study, a small number of coagulase-negative staphylococci (S. epidermidis and S. capitis) that are found naturally on the skin were detected in the water samples obtained after replacing the showerheads with new ones. This may describe the risk of retrograde bacterial contamination of POU filtration units in patients during use because these species are not as common as aquatic microorganisms. However, the number of these staphylococci were small. In addition, as they had not been detected repeatedly in our study, they could be transitory contaminations. Also, the efficiency of POU filter may differ depending on regional water quality. Therefore, the actual function of POU filters should be verified under the operating conditions of each medical facility. In our study, in two-thirds of the samples, the volume of water flowing through the new showerhead was considerably less than that flowing through the original showerheads, which can negatively affect the patients’ experience of showering. Furthermore, interruption of bacterial transmission from water by using POU filters is a short-term solution (Bicking et al., 2017) because POU filtration units need regular replacement of water filters, which increases their maintenance cost. For example, the POU filtration unit that we introduced needs replacement of the old filter capsule for a new one on a bimonthly basis. This may be the major factor that could hinder the introduction of POU filter units in Japanese hospitals because many Japanese hospitals have tight budgets. However, solutions addressing the problem concerning the short lifetime of the POU filters are being developed, such as electrically heatable carbon nanotube POU filters capable of not only physically filtering out Legionella pneumophila from water but also inactivating them on the membrane surfaces of filters using ohmic heating (Oh et al., 2019). This self-cleaning system may contribute to the long-term use

### Table 2: Experimental model verification of the bacteria-filtering effect of the showerheads attached with POU water filter capsules.

| Test microorganism          | Concentration of test organisms used (CFU/mL) | Bacterial count discharged in the test sample from each showerhead (CFU/mL) |
|-----------------------------|-----------------------------------------------|-----------------------------------------------------------------------------|
| Brevundimonas diminuta (ATCC 19146) | 880                                           | 380                                                                         |
| Klebsiella pneumoniae (BWH2) | 530                                           | 440                                                                         |
| Pseudomonas aeruginosa (ATCC 10145) | 740                                           | 310                                                                         |
of POU filters.

Although the POU water filter-based showerhead units have some weaknesses, they are simple and safe devices that can promote the prevention of nosocomial infections due to aquatic pathogenic microorganisms in Japanese healthcare facilities as well. We hope that by introducing adequate financial measures such as reducing the cost of these POU filters, they are widely used in Japanese healthcare facilities in the future.

Acknowledgments
Conflict of interest

Authors were provided with three showerheads incorporated with POU filter capsules (QPoint™) and three replacement POU filter capsules by Nihon Pall Ltd.

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