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Failure of a hollow-fibre shower filter device to prevent exposure of patients to *Pseudomonas aeruginosa*

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SUMMARY

Background: *Pseudomonas aeruginosa* in hospital water is a risk for invasive infection. Point-of-use (POU) filters are used to reduce patient exposure to the organism, and hollow-fibre filters are becoming more popular. However, retrograde colonization of the filter mechanism may contaminate the effluent.

Aims: To assess the efficacy of POU filter head (polysulfone; hollow-fibre matrix) shower filters in preventing the exposure of high-risk patient groups to *P. aeruginosa*.

Methods: Pre-flush (opening the outlet and collecting the first 100 mL of water) samples were analysed to measure *P. aeruginosa* contamination from 25 shower outlets (~21% of all showers on the six wards), with and without a hollow-fibre filter. *P. aeruginosa* was measured in a subset of outlets harbouring *P. aeruginosa* (sampling period 19th August 2019 to 10th January 2020).

Findings: Water from all 25 showers was heavily colonized [>300 colony-forming units (cfu)/mL] with *P. aeruginosa* at the showerhead. *P. aeruginosa* was found in 32% (8/25) of post-filter shower water effluent samples with a geometric mean of $4x10^6$ cfu/mL (N=4) ($6.8x10^4$–$2x10^8$). Filters were sampled at 15–150 days of use (median 15 days), with 26% (6/23) of filter units becoming colonized before the expiry date.

Conclusion: POU filter showerhead units may not be effective in preventing exposure of vulnerable patients to *P. aeruginosa* in hospital water due to retrograde contamination (external contamination of the showerhead passed back to the filter cartridge itself) or failure of the hollow-fibre filter matrix. Reliance should not be placed on the use of hollow-fibre filters to protect patients from exposure to *P. aeruginosa* without repeated microbiological monitoring.

Introduction

Pseudomonas aeruginosa is an opportunistic Gram-negative bacterial pathogen that causes hospital-acquired infection of surgical wounds, blood, the respiratory tract and the urinary tract, particularly in patients in haematology wards and intensive care units (ICUs) [1,2]. *P. aeruginosa* commonly colonizes hospital water systems, and has been associated with outbreaks of infection in vulnerable patients [3]. By analysing the relatedness of *P. aeruginosa* strains from patient infections and hospital water, studies have suggested that water systems, outlets and wet environments are implicated in serious

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infection in immunosuppressed patients [3,4]. The mode and direction of transfer between the patient and the clinical environment is difficult to demonstrate, but many studies have provided evidence of an association between *P. aeruginosa* infection and colonized taps and shower water [4,5]. As such, installation of filters on water outlets has been recommended when disinfection fails to eradicate the organism.

P. aeruginosa tends to become established in distal parts of a water system, such as sinks, taps and showers [3]. Showers are liable to develop *P. aeruginosa* biofilm due to the materials used, low flow rate and operating water temperature of 25—40 °C which favour the growth of this pathogen [6]. The aerosol droplets produced can be inhaled by patients or can contaminate intravenous line insertion sites and damaged mucous membranes, posing a risk, particularly to patients following chemotherapy.

In the UK, remedial actions to mitigate the risks posed by *P. aeruginosa* contamination in water systems are described in Health Technical Memorandum (HTM) 04—01 [7,8]. Where efforts to reduce the number of *P. aeruginosa* using mechanical (shearing by flushing water) and chemical (e.g. chlorine dioxide, silver/copper ion etc.) methods fail, a physical barrier approach, such as a point-of-use (POU) membrane filter unit, may be implemented if water pressure is adequate.

The two main types of POU filter units used on taps and shower outlets in the healthcare setting are membrane filters (disposable or reusable) and hollow-fibre filters. Depending on the manufacturer, standard membrane filter units comprise of a double layer membrane with a pore size of 0.1—0.2 μm which prevents the passage of *P. aeruginosa*, and a pre-filtration layer that retains larger particulates and organic matter [6]. Hollow-fibre filter units consist of a sealed chamber, and the incoming water must pass through 0.1-μm-diameter pores spanning the length of a matrix of hollow fibres before exiting the outlet. Standard membrane and hollow-fibre filter units operate as pass-through water filtration systems, and are prone to biofouling and bioscaling with organic debris and inorganic salts (e.g. calcium/magnesium carbonate). The ability of these filters to sequester *P. aeruginosa* effectively depends on the duration and frequency of use, as well as water quality. The efficiency of membrane POU water filters has been demonstrated, but some studies have reported that *P. aeruginosa* contamination can occur within the recommended term of use given by the manufacturer [9,10].

Hollow-fibre filters are gaining popularity as they allow greater flow of water, especially when water pressure is low [11,12]. The advantage of hollow-fibre filters against conventional flat membrane filters is the attainment of a large membrane surface within a limited volume as the membrane is in the form of hollow-fibre bundles [13]. Polysulfone and polyethylene are commonly used materials in hollow fibres, with average pore diameter ranging from 0.25 to 1.5 μm and from 0.5 to 2 μm, respectively [13,14]. Hollow fibres provide structural strength, and therefore increase the average life of a membrane. In addition, they increase water permeability due to their hydrophilic properties [11]. To determine whether these POU filters continue to prevent egress of *P. aeruginosa* during the manufacturer usage period, this study investigated the efficacy of 25 historically used polysulfone hollow-fibre shower filter units (medical shower filter; 0.1-μm pore size; polysulfone body; antimicrobial silver-impregnated; in-use lifecycle expiry of 92 days) in patient bathrooms in augmented and non-augmented care wards.

Methods

Clinical setting and selection criteria

Twenty-five patient bathrooms were selected at random from six wards with patients requiring augmented care (haematology, elderly care, adolescent haematology/oncology and infectious diseases) at a 700-bed multi-storey building teaching hospital in London, UK. Each ward was a single floor of the hospital building. The bathrooms selected were en-suite for single isolation rooms or those serving shared-occupancy bed bays (rooms with four to six beds). Apart from elderly care, cases of *P. aeruginosa* bacteraemia had occurred in all of the wards in the preceding 2 months. All of the bathrooms had a POU hollow-fibre filter integrated showerhead.

Shower water sample collection and assay by membrane concentration

Prior to sample collection, the showerheads were disinfected by wiping the entire outer surface with a sterile alcohol wipe (70% isopropyl alcohol) and allowed to air dry (~15 s).

The opening of a water sample collection bag (sterile grade) was placed over a showerhead and secured to capture a water sample. An incision was made aseptically to the bottom corner of the bag to create a second opening via which water could be channelled. The shower valve was opened and an aliquot of at least 100 mL of water was collected using the water collection bag into a sample container (pre-dosed with 1 mL of neutralizer solution; composition: 1 g/L sodium thiosulphate, 30 mL/L Tween 80 and 3 g/L lecithin in phosphate-buffered saline). The showerhead was then removed aseptically and placed on a pre-sterilized tray. A second 100 mL water sample was collected in the same manner into a second sample container. These two samples represented 'with/without POU filter' sample arrays, respectively. The showerhead was then re-attached, and the entire surfaces of the showerhead and hose were wiped with a sterile alcohol wipe prior to reinstating the shower. This process was repeated for 25 individual showers within the hospital. This represented 21% (25/119) of showers on the test wards. The sampling period was 19th August 2019 to 10th January 2020. Follow-up sampling was performed for two of the showers 24 days after the first water collection.

Water samples were transferred to a refrigerator (2—8 °C) within 2 h of collection and processed within 24 h. Shower samples (100±5 mL) were concentrated by vacuum filtration (max 65 kPa pressure) through a 47-mm nitrocellulose membrane of pore size 0.45 μm, followed by plating the membrane on to a Pseudomonas C—N agar plate. Plates were incubated aerobically at 37 °C for 48 h prior to counting the colonies. Water sampling and the subsequent procedures were performed in line with HTM guidelines recommended by NHS England [15].

Confirmation of P. aeruginosa isolates

Suspect colonies were distinguished by colony morphology (blue—green/green—yellow/red—brown) on selective agar

(Pseudomonas C–N), harvested for subculture on milk-cetrimide agar (MCA) and nutrient agar in parallel, and incubated at 37 °C for 24 h. Colonies growing on nutrient agar were tested for oxidase reaction, while hydrolysis on MCA was noted.

Isolates demonstrating oxidase-positive reactions and/or hydrolysis of casein on MCA plates were further confirmed by matrix-assisted laser desorption ionization time-of-flight mass spectrometry (MALDI-TOF-MS) analysis (Bruker Daltronics) in line with HTM guidelines. MALDI-TOF-MS analysis was performed as an additional confirmatory step [15].

Measurement of P. aeruginosa

The upper reading/counting limit of samples analysed using the membrane concentration assay technique was 300 colony-forming units (cfu)/100 mL.

A subset of four showers, selected at random, was assayed further by taking a 1-mL aliquot from the original sample and performing serial 1/10, 1/100 and 1/1000 dilutions before plating 100 μL on to Columbia blood agar from the neat, 1/10, 1/100 and 1/1000 arrays. Confirmation of *P. aeruginosa* was done as described previously.

Shower water pressure measurements

Water pressure measurements were performed with a pressure gauge (Bourdon Pressure Gauge 0–4 bar, RSRS Components, UK) on 74 showers from 10 wards. Showerheads were dismantled from the hose, and the screw thread of the pressure gauge was fitted directly to the end of the shower hose. The outlet was opened fully to allow maximum water and pressure values, recorded in bar units, once the gauge stabilized (~5 s). The pressure gauge was dismantled from the shower hose, and its end was disinfected by immersion into absolute ethanol (70% solution) for 2–3 s and then wiping the excess with an alcohol wipe. The showerhead was replaced on to the corresponding hose end, and further disinfected by wiping all external surfaces with a sterile alcohol wipe.

Validation of 70% ethanol sterilization protocol

The efficacy of the ethanol spray/wipe protocol for disinfection of the showerhead prior to sampling was validated in-house using representative shower types and a stainless steel control surface, inoculated with up to 10^6 cfu/cm^2 of *P. aeruginosa*. After spraying with 70% (v/v) ethanol solution and a manual wipe at 10 s, surfaces were sampled by a bead washing technique. Reductions of 6-log$_{10}$ were achieved (publication pending; data available upon request).

Statistical analysis

Chi-squared test with Yates' correction was performed to examine the difference between days of use of the showers that filtered the bacterial load effectively and the showers that failed to filter effectively.

Results

P. aeruginosa was found in the effluent from eight (32%) showers, despite the filter being in place (Table I). Six of those eight showerheads were found to have high bacterial counts (>300 cfu/100 mL). One filter (Shower #16) reduced the *P. aeruginosa* load in the effluent from >300 cfu to 8 cfu, while another (Shower #17) reduced the count to ~100 cfu. These eight showers had been in use for a mean of 60.87 (95% confidence interval 15.3–106) days. Shower #16 and Shower #17 were sampled on the 15th day of use. At the second sampling (39th day of use), these two showers showed *P. aeruginosa* 100 and >300 cfu/mL in the effluent, respectively, with the shower filter in place.

The remaining 18 showers filtered out the *P. aeruginosa* bioburden effectively, despite its presence at high numbers (i.e. >300 cfu/100 mL). The duration of use of the POU filters screened averaged 20.65 (standard deviation 12.57) days. There was no significant difference in the days of use between the showers that filtered the bacterial load effectively and the showers that failed to filter effectively (P=0.075).

P. aeruginosa was quantified in four of eight showers that had *P. aeruginosa* >300 cfu/100 mL with a filter showerhead in place. There was a geometric mean of 4x10^6 cfu/100 mL (6.8x10^4–2x10^8) (Table II).

In total, 74 shower water pressure measurements were taken from 10 floors of the hospital, with values averaging 2.94 bar (range 0.3–3.9). Pressure measurements of the four wards tested in this study were:

- Ward C: 10 shower water pressure measurements, mean 2.43 bar (range 2.3–2.8);
- Ward D: eight shower water pressure measurements, mean 1.8 bar (range 1.6–2.2);
- Ward E: eight shower water pressure measurements, mean 1.17 bar (range 1.1–1.25); and
- Ward F: six shower water pressure measurements, mean 0.83 bar (range 0.8–0.9).

Discussion

Exposure to shower water colonized with *P. aeruginosa* is a potential risk for the development of bacteraemia in immunosuppressed patients [3,4]. In this study setting, the use of hollow-fibre shower filters did not provide assurance of safety for patients in the shower environment. Although not necessarily due to a failure of the filter itself, external contamination and growth inside the showerhead had a similar effect, exposing some patients to high levels of organisms, with a risk of serious subsequent infection in immunosuppressed individuals. Without repeated monitoring, clinical teams may be unaware of the potential source of pseudomonas bacteraemia in vulnerable patients.

The hollow-fibre POU filter showerheads were *in situ* for 3 months before the sampling survey commenced; they replaced showers with non-filtration antimicrobial-impregnated showerhead/hose units.

The hollow-fibre technology was selected due to the high-capacity filtration via the 0.1-μm-diameter pores in the filter matrices, and the long shelf-life of 92 days (manufacturer communications). The POU filters were subjected to routine surveillance to assure efficacy against *P. aeruginosa* during the period of use.

Although the POU filters were effective in removing *P. aeruginosa* from the effluent in the majority of cases, the organism was found distal to the filter in one-third (8/25) of showers. While this study did not explore the sources of

Table I
Presence of *Pseudomonas aeruginosa* in the effluent of hospital shower water fitted with a point-of-use (POU) filter unit at various durations of use

POU shower filter details					Effluent water quality (presence of *P. aeruginosa*)[b]	
Shower ref. number	Ward ref.	Ward specialty	Location of corresponding shower (bay/SIR)	Age of filter (days in use)[a]	Without POU filter (cfu/100 mL)	With POU filter in place (cfu/100 mL)
1	Ward E	Haematology	SIR	15	>300	>300
2	Ward E	Haematology	SIR	15	>300	0
3	Ward E	Haematology	SIR	15	>300	0
4	Ward E	Haematology	SIR	15	>300	0
5	Ward E	Haematology	SIR	15	>300	0
6	Ward E	Haematology	SIR	15	>300	0
7	Ward E	Haematology	SIR	15	>300	0
8	Ward E	Haematology	SIR	15	>300	0
9	Ward F	Haematology	SIR	15	>300	0
10	Ward F	Haematology	SIR	15	>300	0
11	Ward F	Haematology	SIR	15	>300	0
12	Ward F	Haematology	SIR	15	>300	0
13	Ward F	Haematology	SIR	15	>300	0
14	Ward F	Haematology	SIR	15	>300	0
15	Ward F	Haematology	SIR	15	>300	0
16	Ward F	Haematology	SIR	15	>300	8
17	Ward F	Haematology	SIR	15	>300	100
18	Ward B	Elderly care	Bay	45	>300	>300
19	Ward C	Adolescent haematology/oncology	Bay	45	>300	>300
20	Ward C	Adolescent haematology/oncology	Bay	47	>300	0
21	Ward D	Oncology (adult)	Bay	47	>300	0
22	Ward A	Infectious diseases	Bay	47	>300	0
23	Ward F	Haematology	SIR	52	>300	>300
24	Ward C	Adolescent haematology/oncology	Bay	150	>300	>300
25	Ward C	Adolescent haematology/oncology	SIR	150	>300	>300

SIR, single isolation room; cfu, colony-forming units.
[a] Expiry date of POU filter units is 92 days from date of installation (manufacturer specifications). Numbers of *P. aeruginosa* present in shower water with and without a POU filter unit were determined by membrane concentration assay.
[b] Counts depicted as 0 cfu are below the detection limit (1 cfu).

contamination, the isolation of *P. aeruginosa* from filter-treated water was likely due to retrograde contamination from external reservoirs, or failure of the filter matrices in sequestering bacteria.

In this study, a high bacterial burden ($>10^6$ cfu/100 mL) in the pipework proximal to the filter may have overwhelmed the efficacy of the hollow-fibre filter matrix. However, a study using a 0.1-μm porous polyethylene hollow-fibre filter demonstrated >log 6 reduction when challenged with *Klebsiella terrigena* [16]. Retrograde contamination of taps, and even proximal piping, from drains despite POU filters has been reported [17].

POU filters are an alternative to chemical disinfection using chlorine dioxide, hydrogen peroxide or copper–silver

Table II
Quantification of *Pseudomonas aeruginosa* bioburden to determine water quality of the effluent from four showers

Shower description and details			Effluent water quality (presence of *P. aeruginosa*)
Shower ref. number	Ward reference	Ward specialty	cfu/100 mL without POU filter
16	Ward F	Haematology	$6.8x10^4$
17	Ward F	Haematology	$1.45x10^7$
23	Ward F	Haematology	$1.6x10^6$
25	Ward C	Adolescent haematology/oncology teenage cancer	$2.02x10^8$

cfu, colony-forming unit; POU, point of use.

ionization, and are effective when endemic potential pathogens cannot be eliminated [6]. In a surgical ICU, POU filters were associated with elimination of tap water contamination, and a reduction of pseudomonas colonization and infection in patients by 95% and 56%, respectively [9]. Use of 0.2-μm filters in wards in Japan removed all Gram-negative bacterial contamination in water for up to 2 months [6]. Studies in ICUs and bone marrow transplant units found that installation of filters reduced nosocomial pseudomonas infections [18,19].

However, external contamination can affect the efficacy of POU filter devices, and represents an indefinite revenue commitment for replacements. In the present study, the hollow-fibre filters adopted had a specified lifespan of approximately 3 months. Nevertheless, 26% (6/23) of the POU filters became colonized before the expiry date of the device had elapsed. Two of the filters screened in this study were *in situ* beyond the expiry date, and were decommissioned from use immediately by the hospital estates and facilities management. Membrane filter devices are an alternative to hollow-fibre filter units, but contamination with *P. aeruginosa* has been demonstrated to occur within the recommended duration of use [9]. A study from France reported *P. aeruginosa* contamination 4 and 5 weeks after installation [10]. Although the contamination level may be low initially, *P. aeruginosa* can proliferate quickly, presenting a risk for cross-contamination. Polysulfone or polyethylene hollow-fibre filters have practical utility over standard membrane filters in low-pressure water systems, where water output would otherwise be severely attenuated [11,12]. However, they are susceptible to the same problems of external contamination within a few weeks of installation. A laboratory study of experimental contamination of pristine hollow-fibre filter devices (0.2-μm pore size) before placing on uncontaminated taps and showers found that hollow-fibre shower filters were effective in removing *P. aeruginosa* [11]. However, despite a recommended use time of 31 days, hollow-fibre tap filters showed early growth of *P. aeruginosa*, in one case from day 16. There was no back contamination after filters were removed.

The mains water supply of the hospital was screened at the incoming site to the hospital, and found to be free of *P. aeruginosa* (data upon request). In the present study, the water proximal to the filters harboured *P. aeruginosa* 10^6 cfu/100 mL. In cases where *P. aeruginosa* was isolated post-filtration, it could not be ascertained whether the contamination originated from retrograde contamination (e.g. aerosolized droplets from shower trays/drains), translocation through the filter matrix by high-pressure water flow, or as a consequence of perforation of the POU filter cartridge within the body of the showerhead. The pressure of water flow in the test building was below the upper tolerance (5 bar; manufacturer product specification) of the POU filter cartridge. Further exploratory and destructive analysis of the filter device, including microbiological and molecular characterization, is required. Low pressures present another risk because patients may then remove the showerheads and expose themselves to unfiltered shower water colonized by *P. aeruginosa*. Low shower pressures averaged 0.83 bar on Ward F; a haematology area occupied by immunosuppressed patients. In some cases, showerheads had already been removed by the patients when showers were inspected, despite warnings by nurses, ward sisters and wall posters not to do so.

An audit conducted after this study screened patients for rectal colonization between 24th January 2020 and 13th May 2020 (110 days). Six hundred and six samples (groin/rectal swabs) were collected from 155 patients. Four patients were *P. aeruginosa* negative in the first sample, but acquired *P. aeruginosa* during their stay (unpublished data).

Various devices are marketed on the premise of delaying retrograde biofilm formation, but efficacy in use against *Pseudomonas* spp. has not been demonstrated in peer-reviewed studies (e.g. copper inserts for tap outlets and silver-impregnated hoses). Although it is important to demonstrate the source of contamination, investigation of all possible routes of transmission is difficult. Hollow-fibre medical filter devices may be useful in preventing exposure of patients to *P. aeruginosa* from colonized shower water for short periods of use. However, application of POU shower filter units should be complemented with regular water testing, daily cleaning and internal disinfection of filtered water outlets in augmented care wards, especially when growth of *P aeruginosa* persists.

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Conflict of interest statement
None declared.

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