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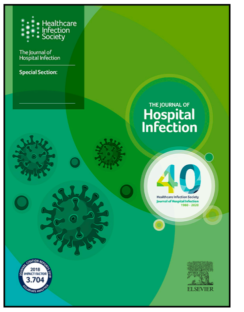

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Failure of a hollow-fibre shower filter device to prevent exposure of patients to *Pseudomonas aeruginosa*

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Summary

Background

Pseudomonas aeruginosa in hospital waters is a risk for invasive infection. Point-of-use filters (POU) are used to reduce patient exposure to the organism; hollow-fibre filters are becoming more popular. However retrograde colonisation 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 *P. aeruginosa* exposure to high-risk patient groups.

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 the total showers on the 6 wards), with and without a hollow-fibre filter. *P. aeruginosa* was measured in a subset of outlets harbouring *P. aeruginosa* (sampling period August 19th 2019 to January 10th 2020).

Findings

All twenty-five shower waters were heavily colonized (>300CFU/mL) with *P. aeruginosa* at the showerhead. *P. aeruginosa* was found in 32% (8/25) of post-filter shower water effluent with a (geometric mean =4x10^{6}(n=4) (6.8x10^4 – 2x10^8). Filters were sampled at (15 – 150) days of usage (median =15) 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 waters due to retrograde contamination (external contamination of the shower head 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 while they are used.

Introduction

Pseudomonas aeruginosa is an opportunistic Gram-negative bacterial pathogen causing hospital-acquired infection of surgical wounds, blood, respiratory and 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 water systems, outlets and wet environments are implicated in serious infection in immune-suppressed patients [3,4]. The mode and direction of transfer between the patient and clinical environment is difficult to demonstrate but many studies have provided evidence of an association between *P. aeruginosa* infection and colonized taps and shower waters [4,5]. Installation of filters on water outlets has been therefore recommended when disinfection fails to eradicate the organism.

P. aeruginosa tends to become established in distal parts of water system such as sinks, taps and showers [3].Showers are liable to develop *P. aeruginosa* biofilm due to the materials used, low flow rates and operating water temperatures of between 25°C and 40°C which favour the growth of this pathogen [6]. The aerosol droplets produced can be inhaled by patients or 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 the Health Technical Memorandum (HTM) 04-01 guidance [7,8]. Where efforts to reduce the numbers 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 faucets 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 0.1 - 0.2µm pore size that 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 into which the incoming water must pass through 0.1µm 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 carbonates). The ability of these filters to sequester *P. aeruginosa* effectively depends on the duration and frequency of usage as well as water quality. Efficiency of membrane POU water filtration has been demonstrated but some studies report that *P. aeruginosa* contamination can occur within the recommended term of usage 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 to attain high membrane surface within a limited volume as the membrane is in the form of hollow fibre bundles [13]. Polysulfone and polyethylene are the two commonly used materials in hollow fibres with average pore diameter range of 0.25 to 1.5 µm and 0.5 to 2µm respectively [13,14]. Hollow fibres provide structural strength, hence increasing the average membrane life. 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, the efficacy of historically used 25 polysulfone hollow-fibre shower filter units (Medical shower filter; 0.1µm pore-size; polysulfone body; antimicrobial silver-impregnated; in-use lifecycle expiry of 92 day) in patient bathrooms in augmented and non-augmented care wards were surveyed.

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 (SIRs) or those serving shared-occupancy bed bays (room with 4-6 beds). Apart from elderly care, cases of *P. aeruginosa* bacteraemia had occurred in all of the wards in the preceding six months.

All 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 (~15s).

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 100mL water was collected using the water collection bag into a sample container (pre-dosed with 1mL neutraliser solutions; composition: 1g/L sodium thiosulphate, 30 mL/L Tween 80 and3 g/L Lecithin in PBS). The showerhead was then removed aseptically and placed onto a pre-sterilised tray. A second 100 mL water sample collected in the same manner into a second sample container. These two samples represent "with/without POU filter" sample arrays respectively. The showerhead was then reattached and the entire surfaces of the showerhead and hose wiped with a sterile alcohol wipe prior to reinstating the shower. This process was repeated for 25 individual showers within the hospital. The number of showers targeted was 25 (21%) of 119 showers on the test wards. The sampling period was August 19th 2019 to January 10th 2020. Follow-up sampling was performed for two of the showers 24 days after the first water collection

Water samples were transferred to refrigeration (2-8°C) within 2 hours of collection and processed within 24 hours. Shower samples (100±5mL) were concentrated by vacuum filtration (max 65kPa pressure) through a 47mm nitrocellulose membrane of pore size: 0.45µm followed by plating the membrane onto a Pseudomonas C-N agar plate. Plates were incubated aerobically at 37°C for 48 hours prior to counting the colonies. Water sampling and following procedures were 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) and harvested for sub-culture onto Milk-Cetrimide agar (MCA) and nutrient agar in parallel and incubated at 37C for 24hours. 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 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 300CFU/100mL.

A sub-set of four showers, selected at random, were assayed further by taking a one-millilitre aliquot from the original sample and performing serial 1/10, 1/100 and 1/1000 dilutions before plating 100uL onto Columbia Blood Agar from the neat, 1/10, 1/100 and 1/1000 arrays. Confirmation of *P. aeruginosa* was done as previously described.

Shower water pressure measurements

Water pressure measurements were performed with a pressure gauge (Bourdon Pressure Gauge 0-4 bar, RS Components) on 74 showers from 10 wards. Showerheads were dismantled from the hose and the screw thread of the pressure gauge fitted directly to the end of shower hose. The outlet was opened fully to allow the maximum water and the pressure values recorded in bar units once the gauge stabilised (~5 seconds). The pressure gauge was dismantled from the shower hose and its end was disinfected by immersion into absolute ethanol (70% solution) for 2-3 seconds and then wiping the excess with an alcohol wipe. The showerhead was replaced onto 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 the disinfection of the shower head 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 seconds, 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 for the difference between days of usage of those shower groups (showers effectively filtering the bacterial load and failing to filter).

Results

P. aeruginosa was found in the effluent from 8 (32%) showers, despite the filter being in place (Table 1). Six out of those eight showerheads were found to have high bacterial counts (>300CFU/100mL). One filter (shower #16) reduced the *P. aeruginosa* load in effluent from >300 CFU to 8 CFU while another (shower #17) reduced the count to ~100 CFU. These 8 showers had been in use for a mean of 60.87 days (95% CI 15.3 to 106). Shower #16 and shower #17 were sampled on 15th day of usage. At the second sampling (39th day), these two showers showed 100 and >300 CFU/mL *P aeruginosa* in the effluent respectively with the shower filter in place.

The remaining 18 showers effectively filtered out *P. aeruginosa* bioburden despite presence at high numbers (i.e. >300 CFU/100mL). The duration of usage of the POU filters screened averaged 20.65 days (SD=12.57). There was no significant difference in the days of usage between those shower groups (showers effectively filtering the bacterial load and failing to filter) (p=0.075).

Table 1. Presence of *P. aeruginosa* of effluent in hospital shower waters fitted with a POU filter unit at various durations of usage. Numbers of *P. aeruginosa* present in shower waters with and without a POU filter unit determined by membrane-concentrations assay.

POU shower filter details					**Effluent Water Quality (presence of *P. aeruginosa*)**	
Shower	Ward Ref.	Ward Specialty	Location of corresponding Shower (Bay/ SIR)	Age of filter (Days	Without POU filter (CFU/100 mL)	With POU filter in place

Ref. number				in use)**		(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

** - expiry date of POU filter units are 92 days from date of installation (manufacturer specifications).

P. aeruginosa was quantified in four out of eight showers that had over 300 CFU/100mL of *P. aeruginosa* with the filtered showerhead in place. There was a geometric mean of $4x10^{6}$CFU/100mL (6.8x10^4 – 2x10^8) (Table 2).

Table 2. Quantification of *P. aeruginosa* bioburden to determine water quality of 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	6.8 x10^4
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

A total of 74 shower water pressure measurements were taken from ten 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: 8 shower water pressure measurements mean 1.8 bar (range:1.6-2.2)
- Ward E: 8 shower water pressure measurements mean 1.17 bar (range:1.1-1.25)
- Ward F: 6 shower water pressure measurements mean 0.83 bar (range:0.8-0.9)

Discussion

Exposure to *P. aeruginosa* colonized shower water is a potential risk for the development of bacteraemia in immune suppressed patients [3,4]. In this study setting, the use of hollow fibre shower filters did not provide assurance of safety for the patient in the shower environment. Although not necessarily due to a failure of the filter itself, external contamination and growth inside the shower head had a similar effect, exposing some patients to high levels of organisms with a risk of serious subsequent infection in immune suppressed 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 three months before the sampling survey commenced; this replaced showers comprising of non-filtration antimicrobial-impregnated showerhead/hose units.

The selection of the hollow-fibre technology was due to the high-capacity filtration via the 0.1um-diameter pores in the filter-matrices and 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 usage.

Although the POU-filters were effective in removing *P aeruginosa* from the effluent in a majority of cases, the organism was found distal to the filter in a third (8/25) of showers. While this study did not explore the sources of contamination, the isolation of *P. aeruginosa* from filter-treated waters 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/100mL) in the pipework proximal to the filter may have overwhelmed the efficacy of the hollow-fibre filter matrix. However, a study using a 0.1µm porous polyethylene hollow-fibre filter demonstrated >log6 reduction when challenged with *Klebsiella terrigena* [16]. Retrograde contamination of taps, and even proximal piping, from drains despite point of use filters has been reported [17].

Point-of-use filters are an alternative to chemical disinfection using chlorine dioxide, hydrogen peroxide or copper-silver ionisation and are effective when endemic potential pathogens cannot be eliminated [6]. In a surgical ICU, point of use filters were associated with elimination of tap water contamination and 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 ICU and bone marrow transplant units found 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 our 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 at weeks 4 and 5 after installation [10]. Although 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. In a laboratory study involving experimental contamination of pristine hollow-fibre filter devices (0.2um pore-size) before placing on uncontaminated faucets and showers were compared. Membrane and hollow-fibre shower filters were effective in removing *P. aeruginosa* [11]. However, despite a recommended use time of 31 days, faucet hollow fibre 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 our survey, the water proximal to the filters harboured 10^6 CFU/100mL *P. aeruginosa*. In cases where *P. aeruginosa* was isolated post-filtration, it could not be ascertained whether the contamination originated by retrograde contamination (e.g. aerosolised 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 showerhead body. 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 characterisation, is required. Low pressures present another risk because patients may then remove the shower heads and expose themselves to unfiltered shower water colonized by *P. aeruginosa*. Low shower pressures averaged 0.83 bar on Ward F a haematology area where immune-suppressed patients stayed. In some cases, shower heads 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 24/01/2020 and 13/05/2020 (110 days). There were 155 patients and 606 samples were collected (groin/rectal swabs). 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* sp has not been demonstrated in peer reviewed studies, for example, copper inserts for faucet 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

No conflicts of interest declared.

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References

[1] G. Ducel, J. Fabry LN. Prevention of hospital-acquired infections. A practical guide. 2nd edition. World Heal Organ 2002. https://doi.org/WHO/CDS/CSR/EPH/2002.12.

[2] Trautmann M, Lepper PM, Haller M. Ecology of Pseudomonas aeruginosa in the intensive care unit and the evolving role of water outlets as a reservoir of the organism. Am J Infect Control 2005. https://doi.org/10.1016/j.ajic.2005.03.006.

[3] Loveday HP, Wilson JA, Kerr K, Pitchers R, Walker JT, Browne J. Association between healthcare water systems and Pseudomonas aeruginosa infections: A rapid systematic review. J Hosp Infect 2014. https://doi.org/10.1016/j.jhin.2013.09.010.

[4] Aumeran C, Paillard C, Robin F, Kanold J, Baud O, Bonnet R, et al. Pseudomonas aeruginosa and Pseudomonas putida outbreak associated with contaminated water outlets in an oncohaematology paediatric unit. J Hosp Infect 2007. https://doi.org/10.1016/j.jhin.2006.08.009.

[5] Venier AG, Leroyer C, Slekovec C, Talon D, Bertrand X, Parer S, et al. Risk factors for Pseudomonas aeruginosa acquisition in intensive care units: A prospective multicentre study. J Hosp Infect 2014;88:103–8. https://doi.org/10.1016/j.jhin.2014.06.018.

[6] Sasahara T, Ogawa M, Fujimura I, Ae R, Kosami K, Morisawa Y. Efficacy and Effectiveness of Showerheads Attached with Point-of-use (POU) Filter Capsules in Preventing Waterborne Diseases in a Japanese Hospital. Biocontrol Sci 2020;25:223–30. https://doi.org/10.4265/BIO.25.223.

[7] Department of Health. Health Technical Memorandum 04-01: Safe water in healthcare premises Part A: Design, installation and commissioning. 2016.

[8] Department of Health. Health Technical Memorandum 04-01: Safe water in healthcare premises. Part C: Pseudomonas aeruginosa – advice for augmented care units. 2016.

[9] Trautmann M, Halder S, Hoegel J, Royer H, Haller M. Point-of-use water filtration reduces endemic Pseudomonas aeruginosa infections on a surgical intensive care unit n.d.:421–9. https://doi.org/10.1016/j.ajic.2007.09.012.

[10] Florentin A, Lizon J, Asensio E, Forin J, Rivier A. Water and surface microbiologic quality of point-of-use water filters: A comparative study. Am J Infect Control 2016. https://doi.org/10.1016/j.ajic.2016.02.028.

[11] Totaro M, Valentini P, Casini B, Miccoli M, Costa AL, Baggiani A. Experimental comparison of point-of-use filters for drinking water ultrafiltration. J Hosp Infect 2017;96:172–6. https://doi.org/10.1016/j.jhin.2016.11.017.

[12] Smith CM, Hill VR. Dead-end hollow-fiber ultrafiltration for recovery of diverse microbes from water. Appl Environ Microbiol 2009;75:5284–9.

https://doi.org/10.1128/AEM.00456-09.

[13] Alla Schmittel, Massimo Basagni, Eric Gaulle TK. Point - of - use Water Purifier With Polysulfone Hollow Fibres. United States Pat Appl Publ 2017;1.

[14] Jun Kamo, Takayuki Hirai, Hiroshi Takahashi KK. Porous Polyethylene Hollow Fiber Membrane Of Large Pore Diameter, Production Process Thereof, And Hydrophilized Porous Polyethylene Hollow Fiber Membranes., 2017.

[15] Department of Health. Health Technical Memorandum 04-01: Safe water in healthcare premises Part B: Operational management. 2016.

[16] Hydreion L. Microbiological Testing of the Sawyer 7/6B Filter. Report No S05-03. 2005.

[17] Bédard E, Prévost M, Déziel E. Pseudomonas aeruginosa in premise plumbing of large buildings. Microbiologyopen 2016;5:937. https://doi.org/10.1002/MBO3.391.

[18] Barna Z, Antmann K, Paszti J, Banfi R, Kadar M, Szax A, Nemeth M, Szego E VM. Infection control by point-of-use water filtration in an intensive care unit - a Hungarian case study. J Water Health 2014;12:858–67. https://doi.org/10.2166/WH.2014.052.

[19] Cervia JS, Farber B, Armellino D, Klocke J, Bayer RL, McAlister M, Stanchfield I, Canonica FP OG. Point-of-use water filtration reduces healthcare-associated infections in bone marrow transplant recipients. Transpl Infect Dis 2010;12:238–41. https://doi.org/10.1111/J.1399-3062.2009.00459.X.