Pseudomonas aeruginosa Infections in the Intensive Care Unit

Facts and Control Measures
Pseudomonas aeruginosa

P. aeruginosa (PA) is a Gram-negative bacillus which, if tolerant of a wide variety of physical conditions, has minimal nutrition requirements, and is a major opportunistic pathogen 1,2. PA appears sporadically in drinking water distribution systems, but seems to occur at a higher frequency in premise plumbing systems compared to water mains 3-9.

PA is one of the most common and problematic bacteria in healthcare facilities, and is responsible for approximately 10-20 % of hospital-associated infections (HAI) (pneumonia, wound infections, blood stream infections and urinary tract infections) in intensive care units (ICUs) 5-10. Length of stay, severity of underlying disease and exposure to invasive procedures, bacterial adherence, virulence factors, and antimicrobial drug resistance are associated with PA infections in ICUs 11,12. The incidence of HAI is 5 - 10 times higher in ICU than general wards 13.

Although endogenous origin was considered as the most relevant route of PA infections, in the last ten years a significant proportion of PA isolates have been shown to stem from the ICU environment and cross-transmission 14,15. Several studies have shown that up to 50 % of hospital acquired PA infections may be derived from the in-premise water distribution system 6,16,17. Unlike patient and pathogen characteristics, environmental factors such as nursing workload or contamination of water outlets can be more easily managed and modified 5.

PA can colonise many types of fluids (even distilled water) and rapidly forms biofilms 4,14,18,19. Moreover, PA can thrive in water fittings including the faucet body, connectors and flow straighteners, sinks, drains, toilets, shower heads and hoses 19-22. Automatic sensor faucets have been shown to be more likely to become contaminated than non-sensor manual outlets 19.

PA has been observed growing within drinking water biofilms 3,24, thus protected and more difficult to eradicate than planktonic bacteria 2,25. PA is resistant to chlorine and other disinfectants used in water treatments 2,26 and may survive in the hospital ward environment even after disinfection 27, increasing the risk of acquisition by patients 28. PA living in biofilms exerts a higher resistance towards disinfectants due to the mechanical protection provided by the biofilm matrix 29-31. It has been shown that the use of sublethal concentrations of chlorine-based oxidising agents (sodium hypochlorite, chlorine dioxide, electrochemically activated chlorine, continuous treatment with 0.15 ppm chlorine or shock treatment with 10 ppm chlorine for 6 hours (h)) can lead to a cyclical regrowth of biofilm after treatment end and the survival of PA living in the biofilm. Under unfavourable operating conditions in a drinking water system, PA has been shown to survive sequentially 24 h 50 parts per million (ppm) chlorine dioxide (ClO₂), 3 minutes (min) 70 °C and 24 h 50 ppm ClO₂ 27.

In a large hospital in Taiwan, a comparative study on infection rates with and without continuous treatment with ClO₂ has been described. Building 1 was continuously treated (over 11 months) with ClO₂ whereas building 2 was not treated. In both cases infections were monitored. The overall rate of non-fermentative Gram-negative bacilli nosocomial infections did not decline after ClO₂ disinfection. Furthermore, PA infection rates increased in both buildings, showing no evidence for a relationship between ClO₂ treatment and PA infection rates 32.

PA is a major pathogen in cystic fibrosis patients with water being a source of infection 2,33. PA is also the organism most commonly detected in gastrointestinal endoscopy-related and bronchoscopy-associated outbreaks 34.

PA may be carried by healthy individuals (2–10 % of individuals, mainly aural) but can be recovered from 50 - 60 % of hospitalised patients 29,35. PA is the main cause of otitis externa (‘swimmer’s ear’), with a magnitude of 2.4 million cases per year and an estimated
outpatient cost of approximately $500 million (table 1). Moreover, PA is a frequent cause of skin infections such as folliculitis. With patients being released earlier from hospital, PA is increasingly recognized as a problematic water pathogen outside of hospital settings.

Due to the increasing numbers of immunocompromised patients and inherent resistance of PA to many antibiotics, hospitals are often facing the real problem of PA infection management as an important public health concern.

**Table 1: Cost overview of Acute Otitis Externa (AOE) in the US, 2003-2007**

<table>
<thead>
<tr>
<th>Number of annual non-hospitalised AOE visits</th>
<th>Mean cost per non-hospitalised AOE visit</th>
<th>Direct annual healthcare costs for AOE</th>
<th>Hours of clinicians’ time annually</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.5 Mio (8.1 visits / 1000 patients)</td>
<td>$200</td>
<td>$0.5 billion</td>
<td>600,000 hours</td>
</tr>
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</table>

**Multi-Drug Resistant PA (MDR PA) in the ICU**

MDR Gram-negative bacteria (MDRGN) are defined as having 3 or more antimicrobial resistance mechanisms affecting different antibiotic classes. The rise of antibiotic resistance in pathogenic bacteria is considered to be an emerging threat to human health and therefore of concern, being associated with increased mortality and limited treatment options. The European Antimicrobial Resistance Surveillance System (EARSS) reported that for Gram-negative bacteria the situation is especially worrying with high, increasing resistance percentages reported from many parts of Europe. For PA the weighted mean percentage for carbapenem resistance increased significantly between 2011 and 2014. A post-antibiotic era – in which common infections and minor injuries can kill – is a real possibility for the 21st century.

Opportunistic Gram-negative bacteria that present increasing resistance issues include Enterobacteriaceae (Escherichia coli, Klebsiella spp., Enterobacter spp., Serratia spp., Citrobacter spp.) and the non-fermenters, PA and Acinetobacter baumannii. Stenotrophomonas maltophilia is inherently MDR, but a less common reported cause of cross-infection. PA strains have developed resistance against commonly used antibiotics, rendering effective treatment increasingly complicated and expensive.

Data collected from MDR Krankenhaus-Infektionen-Surveillance-System (MDRO-KISS) from January 2013 through February 2014 identified 5,171 cases of MDRGN from 341 German ICUs: 848 (16 %) of which were carbapenem-resistant organisms (CRO). Infections with CRO are of particular concern as only a few treatment options remain for patients and outcomes are poor. 61 % of CRO were Pseudomonas spp. (n = 516), mostly PA (n = 493, 58 %), followed by CRE (carbapenem-resistant Enterobacteriaceae) (n=212; 25 %) and Acinetocacter spp. (n = 120; 14 %) dominated by Acinetobacter baumannii (n = 115, 14 %).

A point prevalence study of 56 German hospitals in 2011 found prevalence of resistance was highest in ICUs and higher on medical ICU wards compared with surgical ICU wards. Similar UK results have been found.

A European survey of 19,888 patients, mainly in Belgium and France, showed the highest prevalence of HAI in ICUs (28.1 %). ICUs in acute hospitals and long-term care facilities have higher prevalence of MDR Gram-negative bacteria than general wards, mainly due to their extremely vulnerable population of critically ill patients, the high use of (invasive) procedure and prolonged use of antibiotics. Several factors may influence the spread of multi-drug-resistant pathogens in the ICU, e.g. new mutations, selection of resistant strains, and suboptimal infection control.

MDR PA may be clinically manifested in the lung causing pneumonia, urinary tract, surgical site, bloodstream, cystic fibrosis lung and burns. In a neonatal ICU in Turkey a PA outbreak which involved 12 patients has been reported, with electronic faucets fitting being the likely source, and 8 of 12 invasive isolates being 4 Multi-Resistant Gram-Negative. In 2010, Inglis et al. described an increased incidence of MDR PA in the ICU and High Dependency Unit of an Australian hospital with contaminated aerators and the water system being the possible source. MDR PA is also a rare cause of community-acquired infections.

**Transmission pathways of PA**

Enterobacteriaceae, PA and Acinetobacter spp. may be transferred among vulnerable patients by staff vectors and contaminated equipment. PA and MDR PA are commonly transmitted by contact and aspiration, with the premise plumbing system being one infection source. In such epidemiology, a single clone or small number of clones cause infections in multiple patients without obvious links and over a prolonged period, sometimes extending several years with gaps of several months between cases.

Patient exposure typically occurs while showering, bathing, drinking and through contact with medical equipment rinsed with contaminated water. During daily routines, water is used for personal hygiene. ICU patients often have multiple access devices such as catheters, drains and tracheal tubes. These portals represent potential entrance sites for bacteria. Droplets of contaminated water can inadvertently come into contact with those entrance sites. Morgans et al. reported 14 % of ICU healthcare professionals’ hands were Pseudomonas positive, when washed with contaminated tap water and 12 % positive, when the last contact was with a Pseudomonas positive patient. Patient-to-patient transmission can occur...
via air among patients with cystic fibrosis or via patient hand and environmental contamination. Contaminated bottled water or contaminated water from drinking water dispensers has also been described as a source of hospital-associated Pseudomonas infections in ICUs and Bone Marrow Transplantations (BMTs). Clinical samples isolated from the patients affected.

A prospective multicenter study performed in 10 French ICUs evaluated the contributions of ICU environmental risk factors for PA acquisition and revealed previously contaminated faucet water in the room, and nursing workload were next to individual patient risk factors.

In a Spanish NICU, PA outbreak was described with 9 infections and 1 colonisation. PA had been detected in tap water, which had been used to warm up mothers’ milk. After introduction of sterile water instead of tap water, no further infection cases appeared.

There are 4 main presentations of PA infection:

a) Bacteremia in immunocompromised individuals

b) Pneumonia in cystic fibrosis patients

c) Community-acquired ear and pneumonia infections

d) Hospital-acquired outbreaks, mainly associated with contaminated solutions or medical devices.

Water-associated PA infections

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b) Pneumonia in cystic fibrosis patients

c) Community-acquired ear and pneumonia infections

d) Hospital-acquired outbreaks, mainly associated with contaminated solutions or medical devices.

In all 4 presentations, water containing PA may be an infection source.

Studies have shown that clinical strains of environmental bacteria, including PA and/or their modes of resistance, often originate from the natural environment, including within soil and water. Multidrug-resistant bacteria have been detected from various water sources, including drinking water or tap water. Antibiotic resistant bacteria, at least for some classes of antibiotics, may be more prevalent in tap water than in the water source. Vincenti et al. suggest that high bacterial resistance rates could develop when the original environmental clone already had high rates of antibiotic resistance.

A cross-sectional study evaluating the recovery of Non-Fermenting Gram-Negative Bacteria (NFGNB) in water sources from the hospital environment was performed in different wards of a tertiary care centre and assessed the antibiotic resistance profile. Of 3288 water samples collected, 4.6% were positive for NFGNB with PA being the most represented strain (34.9%) followed by P. fluorescens (17.5%) and Stenotrophomonas maltophilia (10.7%). More than half (55.6%) of isolated strains showed antibiotic resistance with up to 56% of PA in the bronchoscopy unit being antibiotic resistant (48% MDR and 8% extensively drug-resistant).

Of ten patients affected in a multiresistant PA outbreak in a UK adult ICU, typing revealed 2/3 strains of PA detected in water samples matched strains isolated from patients.

Cystic fibrosis (CF) patients become colonised with PA early in life, and the prevalence of colonisation increases with age: 60-80% of CF patients are infected. Although a proportion of CF patients are infected with PA from other patients (cohabitating hospital wards), the main recognised source of infection is water.

Pseudomonas can persist in hospital water systems for extended time periods and can result in outbreak situations. In a PA outbreak in a neonatal unit in Northern Ireland, where 4 neonates died, the typing data of the strains from 2 neonatal units linked the PA strains recovered from the biofilm on the faucet surface and flow straightener, and/or the water samples to the clinical samples isolated from the patients affected.

In a review from different European ICUs a genomic identity between tap water and colonised/infected patients has been shown in 19.2 – 50 % of the reported cases.

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Wound cleansing and PA

Patients with chronic wounds may be frequently colonised by multiple bacterial species including PA, thus delaying or even preventing the wound healing process. A longitudinal analysis of continuous ulceration in a cohort of chronic wound patients found that patients with ≥3 x confirmations of PA in their swabs had a longer wound duration compared to all patients analyzed. Biopsy from chronic venous leg ulcers were investigated by culture and Fluorescence-In-Situ-Hybridization using Peptide Nucleic Acid probes (PNA-FISH). PA was found to aggregate as microcolonies and these wounds had significantly higher numbers of neutrophils present which may be one factor supporting persistent inflammatory response and impaired healing. Diabetic foot infections can process rapidly to irreversible septic gangrene necessitating amputation. An analysis of the polymicrobial nature of diabetic foot infections from 69 swabs and 73 tissues of 42 diabetic patients showed PA as the most frequent aerobic bacteria with a 30.95% distribution. A 6 year antibiotic susceptibility study in a US Burn Centre to analyse MDRO isolates revealed Acinetobacter baumanii as the most prevalent organism, followed by PA. Additionally, transmission of resistance genes between Pseudomonas species and from Pseudomonas spp. to other Gram-negative organisms has been demonstrated and recognised in the burn population. Zhang & Liu analysed 84 patients with 134 burn related sepsis and wound infections, and found multiresistant PA and Acinetobacter spp. the most frequent. Water for wound cleaning should be free of facultative pathogens. The European Practice Guidelines for burn care state that removal of slough, non vital tissue and necrosis should be by abundantly cleaning and cleansing the wound with tap water (filtered), saline solution or sterile water in combination with mechanical debridement in order to reduce the bacterial load. For the cleaning of wounds in immunocompromised patients, only sterile NaCl / Ringer solution or 0.2 µm filtered water should be used in Germany.

Infections are a causal agent of morbidity and mortality for burn patients. In a study of 176 burn care centres in North America, Pseudomonas spp. was seen as the most life threatening infections in thermally injured patients. A 6 year antibiotic susceptibility study in a US Burn Centre to analyse MDRO isolates revealed Acinetobacter baumanii as the most prevalent organism, followed by PA. Additionally, transmission of resistance genes between Pseudomonas species and from Pseudomonas spp. to other Gram-negative organisms has been demonstrated and recognised in the burn population. Zhang & Liu analysed 84 patients with 134 burn related sepsis and wound infections, and found multiresistant PA and Acinetobacter spp. the most frequent.

Lung disorders and PA

Chronic lung infections are associated with increased morbidity and mortality for individuals with underlying respiratory conditions such as cystic fibrosis (CF) and chronic obstructive pulmonary disease (COPD). COPD is a leading cause of mortality worldwide and is associated with morbidity related to acute COPD exacerbations (AECOPD). In an evaluation of 401 patients with AECOPD, 54 (13 %) had a positive PA sputum culture. Resistant PA was isolated in 35/54 (66 %) and these patients were statistically more likely (P = 0.03) to have been exposed to corticosteroids and antibiotics. Sensitive PA (PA-S) was isolated in 18/54 (34 %) of patients, and the presence of PA-S was found to be associated with higher mortality, possibly due to increased virulence in PA-S strains causing acute infections. PA is often isolated in advanced stages of COPD. Of 181 COPD patients analysed, 29 (16 %) had PA in their sputum. After 3 years, 17/29 (58.6 %) patients had died, compared to 53/152 (34.9 %) non-PA patients (P < 0.004). PA is a prognostic marker of 3 year mortality in COPD patients.

Clinical observations link respiratory virus infection and PA colonisation in chronic lung disease, including cystic fibrosis and COPD. The development of PA into highly antibiotic-resistant biofilm communities promotes airway colonisation and accounts for disease progression in patients.

Cystic fibrosis and COPD patients use nebulisers as an integral part of treatment regimens. Nebuliser hygiene is an important, but complicated and time consuming task for patients. Home nebulisers may become colonised and are a potential source of infection as bacteria may colonise both plastic surfaces and human lungs via the formation of biofilms. Woodhouse et al. have shown that the use of sterilising grade filtered water for rinsing of repeatedly used nebulisers significantly reduces bacterial contamination. Moreover, several recommendations support use of sterile water for rinsing of nebulisers, as tap water may harbour non-tuberculous mycobacteria, fungi or PA.

By cleansing wounds with unfiltered or non-sterile water, waterborne microorganisms may colonise wounds, leading to infections.

Cystic fibrosis and COPD patients often carry chronic PA colonisation.
PA infection prevention in the hospital ICU

Water has been demonstrated to be a common source of PA colonisation and infections 6, 37, 38, 80, using genotyping methods and comparing environmental with patients’ PA strains 14, 87. Control of environmental PA transmission is critical, and the rise of antibiotic resistance in pathogenic bacteria including PA, is considered to be an emerging threat to human health 34, 38, 47. The intensive use of antibiotics is creating selective pressure favouring the acquisition and spread of antibiotic resistance among bacteria 52. High awareness for attention to hand hygiene, especially with soap and water, is necessary 79.

Installation of Point-of-Use (POU) Water Filters has been shown to be an effective aid in reducing waterborne PA infection rates 18, 28, 103-107 as well as reducing critical PA contamination events 78, 108-112 (table 2). A review, which assessed the evidence that healthcare water systems are associated with PA infections, was performed by Loveday et al 18. From 196 relevant peer reviewed studies, 25 met the criteria for data strength but only two studies provided plausible evidence for effective control measures. Both studies included Point-of-Use Water Filters 77, 104.

Walker et al. suggest hospitals determine which patients are at risk in augmented units and undertake a review of not just the water system, but also environmental cleaning practices and related best practice to assess possible faecal contamination with patients’ bacteria, to evaluate patient contact with water on particular wards, and to assess other control measures that may be required in order to minimise risks to patients 79.

In a 10 year Swiss study, an increase of hot water temperature to 149 °F (65 °C), eradication of multiresistant PA strains from the environment, and use of Point-of-Use Water Filters in burns and solid transplant organ patient rooms, have been found to be effective infection prevention measures in intensive care units 39.

In an Italian haematology-oncological unit a significant increase of PA positive blood cultures was observed and environmental tests revealed contamination of > 50 % showerheads, faucets, basins and bidets. Measures such as 5 minutes water flushing did not result in a decrease in infection rate. Installation of POU water filters led to a significant reduction in septicemia rate 103.

In a surgical ICU, endemic PA infections were observed for a period of > 24 months, with tap water being persistently colonised with a single PA cloneotype. Different measures to reduce the rate of new PA infections cases, including selective digestive tract decontamination, enhanced hygiene measures and alcohol-based hand disinfection after handwashing, did not reduce the occurrences. Installation of POU water filters led to a significant reduction of colonisation and infection rates. The rate of PA positive patients reduced from 15.5 % in the non-filtration period to 4.3 % in the filter period (p <0.0001). Moreover, overall infections were reduced by 22 % and PA infections by 56 % 104. It may be argued that eradication of PA is not possible in an adult ICU, as already colonised patients may be admitted or there may be transmission between patients from poor hygiene practice. However, providing hygienically controlled water in the ICU for infection prevention purposes should be prioritised 104.

Comparison of a 5-month period with POU water filters installed at all outlets in a subacute care unit with 29 beds showed a significant reduction in ventilator-associated pneumonia (VAP) cases (p = 0.0067), positive cultures for Pseudomonas (p = 0.0004) and upper respiratory colonisation with Pseudomonas (p = 0.0178) 110.

Barna et al. reported the reduction of PA infection rates to 0/100 ICU patient days during the filtration period of 4 weeks versus 2.7/100 patient days over 4 weeks without filters 110.

A reduction of nosocomial PA infections in burn patients from 10 % to 2.5 % 110 and a 50 % reduction of Gram-negative bacteria infections in a bone marrow transplant unit have been reported after installation of POU water filters 107. Furthermore, a prospective clinical study in a liver transplant unit comparing Gram-negative infection and colonisation rates before and after installation of POU water filters reported a reduction of infection and colonisation rates of 47 % per 1,000 patient days during the filtration period 111.

Table 2: Reduction of patient infection/colonisation with Point-of-Use Water Filters.

<table>
<thead>
<tr>
<th>Country</th>
<th>Patient Unit</th>
<th>Effect of POU Filtration</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Italy</td>
<td>Haematology</td>
<td>Reduction of PA positive blood cultures from 8 % and 18 % to 2.7 %</td>
<td>Vianelli et al., 2006 113</td>
</tr>
<tr>
<td>France</td>
<td>ICU</td>
<td>Reduction of PA infections from 8.7/100 patient days to 3.9/100 patient days</td>
<td>Van der Mee-Marquet, 2005 112</td>
</tr>
<tr>
<td>Germany</td>
<td>Surgical ICU</td>
<td>Reduction of PA colonisation by 85 % and infections by 56 %</td>
<td>Trautmann et al., 2008 104</td>
</tr>
<tr>
<td>France</td>
<td>Burns Unit</td>
<td>Reduction of PA infections from 10 % to 2.5 %</td>
<td>Legrand et al., 2009 108</td>
</tr>
<tr>
<td>US</td>
<td>BMT Unit</td>
<td>50 % reduction of Gram-negative bacteria infections</td>
<td>Cervia et al., 2010 107</td>
</tr>
<tr>
<td>US</td>
<td>Subacute Care Unit</td>
<td>90.2 % reduction in VAP cases</td>
<td>Holmes et al., 2010 110</td>
</tr>
<tr>
<td>Hungary</td>
<td>ICU</td>
<td>Reduction of PA infections from 2.7/100 to 0/100 patient days</td>
<td>Barna et al., 2014 106</td>
</tr>
<tr>
<td>China</td>
<td>Liver Transplant Unit</td>
<td>47 % reduction of Gram-negative infection and colonisation rates per 1,000 patient days</td>
<td>Zhou et al., 2014 111</td>
</tr>
<tr>
<td>US</td>
<td>Neonatal ICU</td>
<td>Reduction of positive PA cultures from 1-4 per week to 0 per week</td>
<td>Bicking Kinsey, 2017 113</td>
</tr>
</tbody>
</table>
POU Water Filters are barriers against waterborne microorganisms and may aid in reducing PA rates in high-risk patient groups.

POU Water Filtration recommended as a control measure against waterborne bacteria

World Health Organisation (WHO) recommendations are recognised globally for drinking water quality requirements, and POU water filtration is listed as one suggested control measure for hospitals. In addition, there are national and regional drinking water guidelines, several of which have integrated POU filtration as one control method to prevent transmission of waterborne pathogens to patients and users. PA is an opportunistic bacterium developing antimicrobial resistance and playing a major role in hospital-acquired infections. Prevention of PA infections leads to cost savings.

Financial implications of PA infections and POU Water Filtration

Health care-associated infections (HAIs) can be associated with increased costs in the range of $7,453 - $15,155 per infected patient (table 3). Chronic PA infections in the cystic fibrosis population increased baseline costs by 39%. PA is a major cause of pneumonia in the ICU and following a 6-year study period, patients with PA infection were calculated to have a higher total mean hospitalisation cost at $213,104 vs non-infected patients at $33,851 (P<0.001). Additionally, PA infected patients spent nearly 2 weeks longer in intensive care, and approximately 7 weeks longer in hospital than non-infected patients. MDR-PA had the highest mean incremental cost, which was approximately 7 x the cost of a non-infected patient.

The use of POU water filters was shown to prevent 7.6 infections per 100 patients staying ≥ 3 days in the ICU, and preventing 23 infection cases per year. Given a moderate estimate of the additional cost of any type of nosocomial infection in the range of $3,000, POU water filtration resulted in savings of $69,000 and a net saving of $64,000 when applied in the 12-bed ICU.

A comparison of a 5-month filtration period in a subacute care unit with 29 rooms versus a 1-month non-filtration period found a reduction in total patient costs of $248,136 with net cost savings of $231,036. After a PA outbreak affecting 17/67 patients, Bou et al. calculated €18,408 per case of PA infection, thus being 66% higher than non-infected patients (p = 0.002). Based on these figures a conservative estimate of the extra cost attributable to PA infection in the ICU reached €312,936. The extra length of ICU stay attributable to PA infection was 70 days (p = 0.0001).

Table 3: Cost of nosocomial PA infections and net cost savings with use of POU Water Filters as the control measure. n.a. = not applicable; n.d. = not defined.

<table>
<thead>
<tr>
<th>Year</th>
<th>Preventable Infections by Use of POU Water Filters</th>
<th>Costs due to Infections</th>
<th>Water Filter Costs</th>
<th>Net Cost Savings</th>
<th>Citation</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>23 per year</td>
<td>$3,000 per infection per patient</td>
<td>$5,000 pa for a 12 bed ICU</td>
<td>$64,000 p.a.</td>
<td>Trautmann et al., 2008 114</td>
</tr>
<tr>
<td>2009</td>
<td>n.a.</td>
<td>Average increase of total ICU cost for €18,408</td>
<td>n.a.</td>
<td>n.a.</td>
<td>Bou et al., 2009 126</td>
</tr>
<tr>
<td>2010</td>
<td>16 in 5 months</td>
<td>n.d.</td>
<td>$17,100 for 5 months for 25 POU</td>
<td>$231,046 for 5 months</td>
<td>Holmes et al., 2010 119</td>
</tr>
</tbody>
</table>

Table 3:

- PA is an opportunistic bacterium developing antimicrobial resistance and playing a major role in hospital-acquired infections.
- Tap water is a common source of PA infections in healthcare environments.
- POU Water Filters interrupt the transmission pathway between tap water and patients, and are recommended as an effective control measure which may aid in reducing PA colonisation and infection.
- Prevention of PA infections leads to cost savings.

Typical medical applications of sterilising grade POU Water Filters:

- Wound care
- Food & drink preparation
- Endoscopic reprocessing
- Hand washing
- Shower unit

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