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The Role of Water in Healthcare-Associated Infections

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Abstract

Purpose of review—The aim is to discuss the epidemiology of infections that arise from contaminated water in healthcare settings, including Legionnaire's disease, other Gram-negative pathogens, nontuberculous mycobacteria, and fungi.

Recent findings—*Legionella* can colonize a hospital water system and infect patients despite use of preventive disinfectants. Evidence-based measures are available for secondary prevention. Vulnerable patients can develop care-associated infections with waterborne organisms that are transmitted by colonization of plumbing systems, including sinks and their fixtures. Room humidifiers and decorative fountains have been implicated in serious outbreaks, and pose unwarranted risks in healthcare settings.

Summary—Design of hospital plumbing must be purposeful and thoughtful to avoid the features that foster growth and dissemination of *Legionella* and other pathogens. Exposure of patients who have central venous catheters and other invasive devices to tap water poses a risk for infection with waterborne pathogens. Healthcare facilities must conduct aggressive clinical surveillance for Legionnaire's disease and other waterborne infections in order to detect and remediate an outbreak promptly. Hand hygiene is the most important measure to prevent transmission of other Gram-negative waterborne pathogens in the healthcare setting.

Keywords

biofilm; healthcare-associated infection; Legionnaire's disease

Introduction

The complexity of modern healthcare facilities and increasing proportion of immunologically vulnerable patients make prevention of healthcare-associated waterborne infections a high priority. Several factors make hospital buildings suitable for colonization with bacteria and molds: large, complex water system with areas of low flow predispose to stagnation and biofilm formation; water temperatures that are optimal for healthcare use may also be ideal for bacterial growth. Whereas these conditions exist in other buildings, the

fragility of hospitalized patients and the presence of invasive devices put them at risk for infection with organisms that grow in hospital water. This article reviews the recent epidemiology of waterborne, healthcare-associated infections in the developed world.

Legionella

Legionnaire's disease is an important infection acquired from hospital water, and the one for which detection of a single nosocomial case should prompt an immediate investigation. The disease is typically transmitted to patients through aerosols that arise from showers, ice machines, decorative fountains, humidifiers, and other water sources in hospitals. The first documented nosocomial outbreak occurred nearly a decade before the discovery of the disease and its microbial etiology. When McDade *et al.* [1] identified fastidious thin-walled bacteria, *Legionella pneumophila*, as the cause of pneumonia among 182 people attending the 1976 American Legion Convention the antibody test developed during the investigation was applied to serum specimens from a hospital outbreak. The 1965 outbreak at a Washington, D.C. psychiatric facility comprised 81 cases of pneumonia of unknown cause [2]. Testing demonstrated antibody responses to *Legionella* in 21 out of 23 patient sera [1]. This hospital outbreak of Legionnaire's disease thus became the first of many documented over the past 50 years.

The incidence of Legionnaire's disease in the United States nearly tripled from 2000 to 2009, with only 4% of cases associated with a known cluster [3]. More than 80% of cases are attributable to *L. pneumophila*, and a large majority of those belong to serogroup 1 [4, 5]. The urine antigen assay, which detects only serogroup 1, was responsible for 97% of diagnoses, whereas culture was performed in only 5% of cases [3]. The challenges of culturing the organism make identification of other serogroups and other species uncommon. Pontiac fever is a self-limited hypersensitivity illness that occurs in immunocompetent hosts who are exposed to *Legionella*-containing aerosols, and can have positive urine antigen assays, but do not develop pneumonia [6].

Many components of water systems have been implicated in *Legionella* transmission, including cooling towers, evaporative condensers, water heaters, and the potable water distribution system. When *L. pneumophila* is present in a hospital water system, the patients who acquire the infection generally have medical conditions that contribute to infection susceptibility [7–9], including include organ or stem cell transplantation [10], chronic obstructive pulmonary disease [11], and immunosuppressive therapy (e.g., corticosteroids and TNF inhibitors.) [10–12]. Healthcare personnel are exposed and may seroconvert, but do not usually become ill [13]. Acquiring *Legionella* pneumonia in the hospital conveys an increased mortal risk; the case fatality rate for nosocomial infections in Spain was 31.7% compared to 6.8% for community-acquired disease [14].

L. pneumophila organisms are well suited to the waterworks of hospitals. They multiply between 25 and 42°C and thrive at 35°C, a frequently occurring temperature in manmade systems [4]. They thrive in the stagnant water, scale, or sediment that is found in the dead legs of complex plumbing systems. They flourish in biofilms when a column of water stagnates, as when a hospital fountain is turned off for repairs [9] or when material provides

contaminated biofilms with protection from water currents and decontamination measures [15]. Point-of-use plumbing fixture selection may affect risk for colonization; at some hospitals, hands-free faucets have been shown to have higher *Legionella* contamination rates than manual faucets, and may be more likely to fail disinfection attempts [16–18]. Immunosuppressed patients may acquire the bacteria from hospital water sources via exposure to aerosols from bathing [8, 19–21], steam-heated towels [22], decorative hospital fountains [9, 15, 23], and possibly aspiration of contaminated water [7], among others. Even the distilled water system can become colonized with *Legionella*, as documented in a Quebec City outbreak of *Legionella dumoffii* acquired via respiratory therapy equipment and a room humidifier [24].

Although pediatric legionellosis is very uncommon, neonates have developed *Legionella* pneumonia from delivery in a hospital birthing pool [25] and, more recently, use of a cool mist humidifier filled with contaminated water in a newborn nursery [26]. An additional challenge with pediatric disease is the treatment delay and poor outcome that may result if clinicians do not suspect the infection in this patient population [25, 26].

In nature, *Legionella* grows in association with protozoa, including *Acanthamoeba* spp., *Hartmannella* spp. and *Naegleria* spp., all commonly found in fresh water. Some have suggested that culturing for free-living amoebae from a suspected water source may increase the sensitivity of *Legionella* detection [27].

Early initiation of therapy for Legionnaire's disease is associated with improved survival, but physicians must consider the diagnosis in order to pursue appropriate empiric therapy [28]. Aggressive pursuit of diagnosis in patients who develop hospital-acquired pneumonia is essential for instituting appropriate treatment and recognizing a nosocomial cluster. As part of their evaluation, patients should undergo *Legionella* urine antigen testing, and, if negative, *Legionella* culture and molecular testing from respiratory specimens to detect infection with non-serogroup 1 *L. pneumophila* and less common *Legionella* species [4].

Because preventing and remediating *Legionella* colonization are of utmost concern, guidelines for hospital construction prioritize *Legionella* risk reduction [29, 30]. Some hospitals use systemic disinfection measures such as copper-silver ionization, chlorine dioxide, or monochloramine. These disinfection systems are reviewed thoroughly by Lin *et al.* [31] and Stout *et al.* [32]. Of note, monochloramine use in municipal water has been shown to reduce *Legionella* infection risk in hospitals [33, 34].

Breakthrough *Legionella* has been reported with every modality of disinfection. A recent outbreak involving 21 patients and 5 attributable deaths at the Veterans Affairs Pittsburgh Healthcare System was notable in that 29 out of 44 water samples (66%) were positive for *Legionella* [23]. This proportion far exceeded the 30% threshold of 'heavy colonization' proposed by Yu and colleagues above which nosocomial cases of Legionnaire's disease occur more frequently [35, 36]. Some water isolates matched the outbreak strain, despite appropriate copper and silver levels [23]. A filter and ozone generator failed to prevent contamination of a decorative wall fountain that caused infection in stem cell transplant

recipients [9]. A larger outbreak stemmed from contamination of another hospital fountain despite the presence of a regularly maintained copper-silver ionizer [15].

When a water system is already contaminated with *Legionella*, options include super-heating and flushing the system with or without shock chlorination.[20] These methods have been effective in terminating existing outbreaks.[19, 31, 32] Preventing back-flow of heated water into the cool water system limits the possibility of producing ideal temperature conditions for *Legionella* growth. [20, 37] Hospitals that utilize a systemic disinfection modality should monitor the intervention (e.g., ion levels) and consider periodic cultures to establish its effectiveness.[31]

Hospitals providing care for immunocompromised patients must conduct close clinical surveillance for Legionnaire's disease among that patient population.[10, 38] The US Centers for Disease Control and Prevention (CDC) recommends that facilities that have had a nosocomial outbreak of Legionnaire's disease conduct ongoing microbiologic surveillance to detect recontamination of their water supply.[10, 38] The use of environmental surveillance for primary prevention, when there has been no outbreak, remains an area of controversy.[36]

Other Gram-negative bacteria

Several clinically important Gram-negative bacterial species are well adapted to colonize the biofilms of water systems, and their presence has been associated with sporadic infection and outbreaks in hospitalized patients. Many genera are associated with transmission via hospital water, including *Pseudomonas*, *Stenotrophomonas*, *Acinetobacter*, *Sphingomonas*, *Burkholderia*, and *Achromobacter*. Most Gram-negative waterborne infections likely go unrecognized unless they occur in a cluster.

Pseudomonas species are commonly associated with biofilms in hospital water sources [39]. Therapy pools, tubs, and daily bathing in bed can be sources of transmission [38, 40–42]. *Stenotrophomonas*, *Chryseomonas*, and other waterborne bacteria have caused outbreaks in neonates with intravenous lines or other invasive devices who were bathed in tap water [43, 44]. On one neonatal ICU in Belgium, pseudomonal infection was linked to the thawing of frozen blood products in a contaminated water bath [45]. In the presence of surgical incisions, invasive devices, or significant immune compromise, an exposure that would normally be deflected by the body's surface defenses may cause invasive infection. In order to reduce the risk of transmission from these sources, sinks and wash basins should be cleaned and disinfected regularly as part of routine hospital environmental cleaning [38]. There are not yet data to support use of chlorhexidine baths to reduce the risk of infection with waterborne bacteria.

Hand hygiene of healthcare personnel is the most important measure to prevent Gram-negative hospital-acquired infections [38]. Ironically, transmission in the setting of appropriate hand hygiene may occur when hands become contaminated during hand-washing in a sink with a contaminated aerator, faucet, or drain. This method of transmission has been reported in several outbreaks [16, 18, 46–55]. A hospital in Toronto recently

identified hand-washing sinks as a key reservoir for nosocomial transmission of multidrug-resistant *Klebsiella oxytoca* following an outbreak among 66 patients [56]. Hota et al reported contamination of an intensive care unit sink with a outbreak strain of multidrug-resistant *Pseudomonas*; fluorescein injection into sink drains demonstrated splash-back up to 1 m from the sink when the water was running [57]. Remediation of outbreaks due to sink contamination may require disassembly and replacement of plumbing components [56], redirection of the faucet water jet [57, 58], replacement of the sink [48], or rearrangement of the surrounding space [57]. Hospital waste water can also lead to outbreaks when blockages and leaks occur, as happened in one hospital due in part to a sharp-angled pipe junction; splash-back from shower drains and toilets may have caused contamination of patient materials placed nearby [59].

Patients can acquire waterborne bacteria from healthcare devices that contain liquid but with which they do not have direct contact. Contamination of the water used in hemodialysis equipment has frequently been reported as a cause of bloodstream infections in dialysis patients [60]. A blood gas analyzer with a contaminated water reservoir was linked to a prolonged ICU outbreak of *Burkholderia cepacia* [61]. Room humidifiers have been implicated in transmission of Gram-negative organisms, in some cases despite use of sterile water. Colonization occurs after about 5 days of continuous use, possibly from room particles and from hand contamination during filling [62]. Cool mist humidifiers, which are difficult to clean and disinfect properly, have caused outbreaks of Legionnaire's disease, [24, 26] *Pseudomonas*, *Acinetobacter* [63, 64], and other Gram-negative organisms, with little actual rise in room humidity [63]. The evidence suggests a highly unfavorable risk-benefit ratio of room air humidifier use in hospitals.

Mycobacteria

Nontuberculous mycobacteria (NTM) are hardy organisms that are present in municipal water, survive in hot water systems, and resist chlorination [65, 66]. Plumbing features that encourage the growth of *Legionella* species, such as dead legs, stagnation, and warm water, also foster proliferation of NTM. Because the organisms occur frequently in hospital tap water [67–70], many true outbreaks and several pseudo-outbreaks with NTM have been reported. Hospital-associated outbreaks and sporadic cases have included central line infections, sternal wound infections, cosmetic surgery-associated soft tissue infections, and bloodstream infections related to dialysis [71–80]. Most reported outbreaks involved exposure of invasive devices or nonintact skin to tap water. Wallace *et al* [80] reported eight outbreaks involving 71 patients with NTM infections after cardiac bypass surgery. Eighty per cent of isolates were from southern U.S. coastal states, where NTM infections have the highest incidence [81]. Sources of transmission included tap water used to cool the cardioplegia solution and ice machines; in both cases contamination was thought to originate from the municipal water supply [80]. A cluster of 34 patients who underwent liposuction developed *M. chelonae* cutaneous abscesses. Patient isolates matched those of bacteria detected in water pipes in the physician's office, and the investigation suggested that surgical instruments rinsed in that water were inadequately disinfected [78]. Five hemodialysis patients developed *M. chelonae-abscessus* infections linked to high-flux dialysis machines in a single center, where a contaminated water spray was used for reprocessing dialyzers, and

the disinfectant solution had inadequate germicidal activity against mycobacteria [77]. Pseudooutbreaks with NTM are typically due to tap water rinsing or contamination of diagnostic testing equipment. In one hospital, the bronchoalveolar lavages of 9 patients over a month grew *M. chelonae* in the absence of typical symptoms; investigation revealed that the incoming water line of an automated bronchoscope cleaner was the source of this pseudooutbreak [74].

Protozoa

Nosocomial transmission of intestinal protozoa has become uncommon in developed countries with sanitary hospital water supplies. Poor sanitation increases risk of waterborne infection, but some organisms are hardy enough to survive even in the presence of disinfection [82]. An unusual outbreak of *Cyclospora cayatenensis* was traced to a contaminated rooftop water supply and caused diarrheal illnesses among 17 medical residents and three staff members in a Chicago hospital [83]. After *Cryptosporidium parvum* caused a massive community outbreak in Milwaukee, Wisconsin, that disproportionately affected immunocompromised persons [84], water treatment regulations implemented in the wake of that outbreak have successfully prevented further municipal water-related outbreaks in the United States [85]. *Cryptosporidium* can be spread in hospitals to elderly or immunocompromised patients through contaminated food or water, although a number of reports implicate transmission via contact [86]. In one outbreak in Denmark, a patient who had HIV/AIDS and *Cryptosporidium* infection contaminated a hospital ice machine, leading to 19 infections [87].

Fungi

Fungal contamination of water in the healthcare environment is considered a potential source of nosocomial infection. The presence of opportunistic molds such as *Aspergillus* and *Fusarium* has been reported in hospital water and plumbing fixtures [88–90]. Although airborne spores are thought to be the primary mode of nosocomial transmission, those spores may derive in part from water sources within the hospital [91]. Molecular typing has been used to link waterborne isolates with patient infections in a few cases. An investigation of fusariosis in a Texas hospital demonstrated *Fusarium* species in a majority of environmental samples; two water isolates matched patient isolates, suggesting nosocomial acquisition from water or a plumbing fixture [89]. *Phialemonium* bloodstream infections in dialysis patients were linked to reflux of contaminated fluid from a waste water line into the patient dialysis line during priming [92], a mechanism that has also been implicated in bacterial bloodstream infections and transmission of hepatitis C in this population [93, 94]. Because the role of water contamination with molds in the epidemiology of patient infections remains unclear, current guidelines do not recommend reducing exposure of vulnerable patients to hospital water, but rather focusing on using best practices in structural and engineering controls to limit transmission to patients [29, 38, 95].

Conclusion

No single approach guarantees that hospital water will be safe for vulnerable patients, but a combination of engineering and hygiene measures and clinical strategies can minimize the risk. Engineering measures in the built environment include avoidance of features in plumbing systems that predispose to stagnation, maintenance of separate cold and hot water systems until near the point of use, and thoughtful construction of wastewater pipes to avoid blockages. Decorative fountains should not be placed inside healthcare facilities [9, 29]. Careful planning should be given to sink design, avoiding high flow over drains, proximity to critical patient care areas, and possibly hands-free faucets. Hygiene measures include routine cleaning and disinfection of sinks and plumbing fixtures, proper disinfection of equipment that is rinsed in tap water, and, most importantly, healthcare personnel hand hygiene to prevent transmission of pathogens derived from moist sources to patients. Clinical strategies include aggressive surveillance for nosocomial waterborne infection, including testing patients who develop nosocomial pneumonia for *Legionella* species, and conducting prompt investigations if a single hospital-acquired case is suspected. Protection of central venous catheter sites from exposure to tap water, as recommended by current guidelines [96], may prevent some bathing-related outbreaks. Water disinfection systems can be implemented as a primary or secondary preventive measure, but even expensive, potent systems have been documented to fail. Most essentially, infection control specialists should be quick to respond to increases in rates of known and emerging waterborne pathogens.

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- Healthcare facilities must conduct careful clinical surveillance for legionellosis, including diagnostic testing specific for *Legionella* in all patients who develop nosocomial pneumonia.
- Hospitalized patients who are highly immunocompromised or have invasive devices are most susceptible to infections with waterborne pathogens that can evade the body's normal defenses.
- Devices that aerosolize water in the presence of patients, such as room humidifiers and decorative fountains, pose a risk of infection with waterborne pathogens and are not recommended for use in hospitals.