# Waterborne Nosocomial Infections

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Waterborne pathogens cause infections in health-care facilities. Despite guidelines addressing these pathogens, outbreaks and pseudo-outbreaks continue to occur. We reviewed recent reports of infections caused by *Pseudomonas aeruginosa, Stenotrophomonas maltophilia, Chryseobacterium* species, nontuberculous mycobacteria, and *Legionella* species. *Mycobacterium avium* complex (MAC) infection in HIV patients has been linked to hospital water distribution systems; molecular subtyping showed that MAC isolates in patients and hospital water were identical. In immunosuppressed patients, *Fusarium* infection has been linked to the hospital water distribution system; again molecular subtyping showed that isolates from patients and the water supply were identical. Parasites, especially *Cryptosporidium*, and viruses have also been implicated in nosocomial infection. Transmission occurs via contact, ingestion, aspiration, or aerosolization of potable water, or via the hands of health-care workers. Interventions designed to interrupt transmission of waterborne pathogens have included the use of antimicrobial handwashes, targeted disinfection of the water supply, and, in high-risk populations, restricting the use of tap water.

## Introduction

The potable water distribution system of a health-care facility (HCF) provides for hydration and hygiene of both patients and health-care workers (HCWs), and is presumed to be safe. Ironically, however, in the case of some infected patients, that very water is the source of the pathogen(s) responsible for their suffering.

Immunocompromised patients are at high risk to develop nosocomial infections due to waterborne pathogens. Neonates and patients in intensive care units (ICUs) are at highest risk.

Potable water harbors a variety of microorganisms, particularly in the slime layer, or biofilm, of plumbing systems. Waterborne pathogens that are sources of nosocomial infection include aerobic gram negative bacilli (Table 1) and nontuberculous mycobacteria; recent reports implicate fungal and viral pathogens.

Facility-system water is delivered to patients via the rinsing of medical equipment (*eg*, tube feed bags, respiratory equipment, endoscopes) with tap water; the ingestion of contaminated water or ice; and direct contact with contaminated water (*eg*, water baths or whirlpools). To prevent waterborne infections, some guidelines—including rinsing medical equipment with sterile water and using dry-warming devices to heat fluids—have been established. However, despite the use of such guidelines, nosocomial waterborne outbreaks continue to occur.

## *Pseudomonas aeruginosa*

*Pseudomonas aeruginosa* is well established as a waterborne pathogen in the hospital setting (Table 2). In the past two years, reports from four countries—France, Belgium, Australia and the United States—have linked nosocomial outbreaks to water sources contaminated by *P. aeruginosa*. In three of these reports, the hands of HCWs were implicated in the transmission of the organism.

One outbreak was due to multidrug-resistant *P. aeruginosa* and occurred in a French neurosurgery unit [1]. *P. aeruginosa* was isolated from 36 patients with urinary tract infection (UTI), pneumonia, or sinusitis. Environmental cultures yielded multidrug-resistant *P. aeruginosa* from enteral tube-feed solutions and from the facility's tap water. DNA macrorestriction analysis showed that the isolates from tap water were identical to the patient isolates. The sinks were presumably the main source, and *P. aeruginosa* was likely transmitted to the patients via the hands of the HCWs or via nutrition solutions contaminated by tap water. Disposable containers for enteral feeds replaced reusable ones, which were rinsed with tap water; sinks were also replaced. The outbreak ceased.

A pediatric oncology unit in Australia and a pediatric surgery unit in France were the sites of two other outbreaks due to *P. aeruginosa* [2,3]. The outbreak in Australia included patients with bacteremia, skin infection, vascular catheter-site infection, and UTI [2]. The outbreak source was determined to be bath toys. A case-control study showed a significant link between infection and the use of bath toys and duration of stay. Pulsed-field gel electrophoresis (PFGE) subtyping showed that the strains of *P. aeruginosa* isolated from the toys, toy box, and patient isolates were identical. The French pediatric surgery unit experienced an outbreak of 14 UTIs over a 3-month period. Of the 14 patients, 11 had urinary catheters; tap water was used to provide urinary catheter care [3].

**Table 1. Gram-negative bacilli linked to waterborne infection**

| Gram-negative bacilli | Water source(s) in hospital |
|---|---|
| *Acinetobacter* species | Sink or wash basin; distilled, sterile, and nonsterile water |
| *Burkholderia cepacia* | Distilled, sterile, and nonsterile water |
| *Chryseobacterium* species | Potable water |
| *Ewingella* species | Ice baths |
| *Legionella* species | Potable water, ice machines |
| *Pseudomonas* species | Potable water, liquid solutions |
| *Serratia marcescens* | Liquid solutions including medications; sink or wash basin |
| *Stenotrophomonas maltophilia* | Potable water; sink or wash basin |

Multiple isolates of *P. aeruginosa* were isolated from both the patients' urine and the tap water. PFGE typing demonstrated that isolates from the tap water were identical to isolates from the patients. Infections were caused by direct contamination from the tap water or indirect contamination via HCWs' hands after washing. Use of sterile water for urinary catheter care, replacement of all faucets that were 10 or more years old, and reinforcement of hygiene measures were used to halt this outbreak.

In an outbreak of *P. aeruginosa* infection in a 15-bed neonatal intensive care unit (NICU) in Belgium [4], four newborns were colonized or infected with *P. aeruginosa* within a week. Each of the affected newborn infants had received a transfusion. A water bath for heating blood components was contaminated with *P. aeruginosa*. Antibiogram and random amplification of polymorphic DNA (RAPD) showed that the infection strain was identical to the strain in the water bath. However, not all neonates who received blood products warmed in the water-bath became infected, and it was theorized that the source of transmission may have been the hands of the HCWs, following their exposure to the water-bath. After replacing the water-bath with a dry heating incubator and enforcing standard infection control procedures, no further cases occurred.

Finally, over a 6-week period, four deaths due to *P. aeruginosa* bloodstream infection occurred in a US NICU [5]. The epidemic strain was recovered from one HCW's hands and two environmental sources, a ventilator flow meter and a faucet handle.

## Other Gram-negative Bacteria

*Stenotrophomonas maltophilia* is a nonfermentative, gram-negative bacillus that can be isolated from water. Most human isolates represent colonization, rather than infection. Factors for highest risk are underlying malignancy, neutropenia, chemotherapy, indwelling catheters and prior antimicrobial therapy. The major clinical syndrome is bacteremia; the typical portal of entry is a vascular catheter.

In a surgical ICU, seven patients were infected or colonized with *S. maltophilia*. Environmental cultures from sinks and faucet aerators revealed *S. maltophilia*. PFGE subtyping showed that the patients were colonized or infected with five different strains, while environmental sources yielded four different strains. In two cases, the strain of *S. maltophilia* isolated from the faucet aerator in the patient's room matched the strain colonizing the patient [6]. These strains may have been transmitted to the patient by transient colonization of the hands of HCWs, or through direct contact with the source, when patients bathed in the tap water.

In an outbreak of *S. maltophilia* in a Netherlands NICU [7], four infants were colonized and a fifth died due to *S. maltophilia* septicemia. *S. maltophilia* was cultured from tap water from three outlets in the NICU. Environmental and clinical isolates yielded identical banding patterns on RAPD analysis. The probable method of transmission was bathing of the infants in contaminated tap water. Limiting the use of tap water for hand washing, enforcing hand disinfection, and the use of sterile water for washing the infants controlled the outbreak.

*Chryseobacterium* (*Flavobacterium*) species are gram-negative bacilli that occasionally colonize the respiratory tract of neonates or adults in ICUs. They have been recovered from HCF water sources. Two patients in a burn unit developed sepsis with *Chryseobacterium* [8]. *Chryseobacterium meningosepticum* was isolated from the hot water samples taken from the bathtub and water supply in the room. Arbitrarily primed polymerase chain reaction (AP-PCR) typing showed that the water isolates were identical to the organism infecting the patients.

## *Mycobacterium*

*Mycobacterium* species other than *Mycobacterium tuberculosis* (non-*tuberculosis Mycobacterium*, NTM) are commonly found in water, and can be a rare source of nosocomial infection. Alternatively, NTM can be a colonizing organism isolated from a nonsterile site or a laboratory contaminant (Table 3). Hot-water systems are often the source of these organisms. Some NTM (*M. xenopi*, *M. smegmatis*, *M. avium*) can be thermophilic, surviving and growing in temperatures $\geq 45°C$. Nonthermophilic NTM (*M. kansasii*, *M. gordonae*, *M. fortuitum*, *M. chelonae*, *M. abscessus*, *M. mucogenicum*) are more often found in cold water systems. *M. avium* grows well in both high and low temperatures, and thus can be found in both hot-water and cold-water systems.

NTM have been identified as the source of cardiac and plastic-surgery infections, dialysis infection and injection-site abscesses. Municipal water systems are a major environmental reservoir for NTM. In 83% of US dialysis centers, the municipal water supply is colonized by NTM [9]. NTM are resistant to a wide variety of disinfectants, including chlorine, glutaraldehyde, and formaldehyde.

**Table 2. Nosocomial outbreaks due to *Pseudomonas aeruginosa*; reports since 1997**

| Year | Country | Hospital unit | Infection* (number) | Source | Transmission† | Subtyping |
|---|---|---|---|---|---|---|
| 1998 | France | Pediatric surgery | Urinary tract (14) | Tap water | Urinary tract care, HCW hands | PFGE |
| 1998 | France | Neurosurgery | Urinary tract, sinusitis, pneumonia (36) | Tap water, sink traps | Enteral feeding bags rinsed with tap water, HCW hands | PFGE |
| 1998 | Belgium | Neonatal ICU | Bacteremia, umbilical catheter (4) | Water bath | HCW hands | RAPD |
| 1998 | Australia | Pediatric oncology | Bacteremia, skin, line, urinary tract (9) | Tap water | Water-retaining bath toys | PFGE |
| 1997 | United States | Neonatal ICU | Bacteremia (4) | — | Faucet handle, flow meter, HCW hands | — |

*Type or site
†Presumed mode of transmission
HCW—health-care worker; ICU—intensive care unit; PFGE—pulsed-field gel electrophoresis; RAPD—random amplification of polymorphic DNA
*Data from* Ferroni *et al.* [3], Bert *et al.* [1], Muydermans *et al.* [4], Buttery *et al.* [2], and Matyas [5]

**Table 3. Mycobacterial infections, pseudoinfections linked to a hospital water wource**

| Year | NTB species | Number infected | Infection type | Underlying disease |
|---|---|---|---|---|
| 1999 | *M. fortuitum* | 1 | Breast abscess, bacteremia | Breast cancer, leukemia |
| 1998 | *M. kansasii* | 14.3/1000 cultures | Pseudo-outbreak | — |
| 1994 | *M. avium* | 29 | Disseminated | AIDS |

NTB—non-*tuberculosis Mycobacterium*
*Data from* Kauppinen *et al.* [10], Brook *et al.* [11] and von Reyn *et al.* [12•]

Pseudo-outbreaks of NTM have been linked to rinsing medical equipment with tap water, and contaminated hospital solutions, including medications.

A patient with leukemia and a recent history of breast cancer was treated with surgery, radiation and chemotherapy, and developed a fistula with a breast abscess that yielded *M. fortuitum* on culture [10]. Environmental cultures revealed the presence of *M. fortuitum* from the shower head this patient used in the HCF; AP-PCR typing indicated that the environmental isolate was identical to the patient's strain.

At a US Veteran Affairs hospital, the isolation rate of *M. kansasii* from cultures doubled in one year [11]. Review of the clinical course of the patients was inconsistent with infection, and laboratory contamination could not be documented. As a water reserve, this hospital used underground holding tanks, which were cycled biweekly. Overgrowth of *M. kansasii* may have occurred when the tanks were not cycled on schedule. It was hypothesized that patient consumption of potable water prior to the obtaining of sputum specimens was the source of a pseudo-outbreak. Biweekly cycling was resumed, and patients were instructed to rinse their mouths with sterile water prior to sputum-specimen collection; the apparent pseudo-outbreak disappeared.

Acquisition of *M. avium* complex (MAC) infection by patients with human immunodeficiency virus (HIV) has been linked to hospital hot-water distribution systems [12•]. Strains isolated from HIV patients were identical to those isolated from the hospital's water system. Thus, recent acquisition of the organism, rather than reactivation of latent infection, was the likely pathogenesis [13]. The gastrointestinal tract is the likely portal of entry in AIDS patients, although aspiration is a possibility. Interestingly, co-infection with *Legionella*, a well-known waterborne pathogen, and MAC has been reported, suggesting that the water supply was the source of both organisms [13].

## *Legionella*

One of the most pressing and high-profile problems, with respect to nosocomial waterborne infection, is Legionnaires' disease acquired from exposure to the potable water supply. Although the link to the water supply was first made in 1982 [14], outbreaks continue to occur, and numerous outbreaks have been reported since 1998. Pediatric hospitals, rehabilitation centers, and long-term care facilities are now reporting cases linked to the potable water supply, expanding the scope of nosocomial Legionnaires' disease. Aspiration, not aerosolization, is the mode of transmission of nosocomial infections. Transplant recipients appear to be at highest risk, although patients with chronic lung disease and those likely to undergo procedures that lead to aspiration are also at high-risk.

A major feature differentiating nosocomial Legionnaires' disease from other waterborne infections is that the correct diagnosis of nosocomial Legionnaires' disease is easily overlooked. The clinical and radiological manifestations are nonspecific, and specialized microbiologic studies are necessary. In a Centers for Disease Control and Prevention (CDC) study of hospitals in the National Nosocomial Infections Surveillance system, only 14% of hospitals routinely tested sputum specimens for *Legionella* [15••]. Disturbingly, of hospitals reporting cases of nosocomial Legionnaires' disease, 23% had no *Legionella* diagnostic tests routinely available. Despite guidelines issued jointly by the CDC and the Hospital Infection Control Practices Advisory Committee, 21% of hospitals experiencing nosocomial Legionnaires' disease never cultured their own water supply [15••].

In two reports from the CDC, outbreaks of nosocomial Legionnaires' disease occurred over a period of 12 and 17 years before intervention measures were applied [16,17]. Most of these cases were retrospectively diagnosed, some by autopsy. *Legionella* was rarely considered as a cause of nosocomial pneumonia, and without this high "index of suspicion," diagnostic *Legionella* testing was not performed.

We have proposed that environmental cultures be used as a screen to stimulate the index of suspicion and application of diagnostic *Legionella* testing for patients with nosocomial pneumonia [18]; such an approach has been enacted in Allegheny County (Pittsburgh), PA [19] and Maryland. The CDC recently proposed that bone marrow transplant centers routinely culture their water supply [20].

Because the reservoir of nosocomial Legionnaires' disease has been identified so precisely, prevention is possible by disinfecting the water supply. Superheat-and-flush is a tedious approach, but it has proven to be successful as a short-term method for terminating outbreaks [21]. Copper-silver ionization has displaced hyperchlorination as the modality of choice for long-term control [21].

## Fungi

Historically, nosocomial infections caused by fungi have been attributed to exposure to airborne spores associated with hospital construction and renovation. *Aspergillus fumigatus* is the most common species reported to be involved; however, *Aspergillus flavus* has also been linked to the hospital environment [22••]. A provocative study by Anaissie and colleagues [23] suggests that hospital water systems may also be a source for the transmission of fungi. *Aspergillus* species and *Fusarium* species were isolated from the water distribution systems in hospitals in Texas and Arkansas. Fungi were recovered from 52% (14 of 27) of water samples. *Aspergillus terreus*, *Aspergillus niger*, and *Fusarium* species were cultured from shower heads; 43 *Fusarium* infections were diagnosed, from 1986 through 1995, at one Texas hospital. Culture of the water from a shower in the patients' rooms yielded *Fusarium*, and airborne dissemination of *Fusarium* after showering was documented [23–25]. Molecular methods showed that patient isolates were identical to environmental isolates.

## Viruses

Viruses are not a common source of water-associated nosocomial infections, although they have been identified as the source of waterborne-pathogen outbreaks in the community [26]. During such outbreaks, cases generally present as gastrointestinal illnesses. Because stool cultures are not routinely assessed for viruses, these outbreaks are easily overlooked. In a study of six patients who developed gastroenteritis in a French hospital [27], a small round structured virus (SRSV) was cultured from the common drinking fountain and from patient stools; oral-fecal transmission could not be excluded. Heat-shock and chlorine treatment of the potable water system was implemented as the disinfection method.

## Reservoirs

Water distribution systems are often identified as reservoirs for nosocomial transmission. Any portion of the system, from the hot water tank to the faucet, may be linked to infection. Sinks, drains, and faucets have been linked to outbreaks of gram-negative bacteria. Splashback from sink drains can potentially contaminate HCWs' hands. HCWs' hands can transmit pathogens to patients after they come in contact with contaminated water. Contamination of medical equipment after water contact (*eg*, rinsing of respiratory equipment, enteral feed containers, endoscopes, and bronchoscopes with tap water), with resulting nosocomial infection, has also been well documented. Faucet aerators have been identified as possible reservoirs for waterborne pathogens [6], although many HCFs neither disinfect nor remove faucet aerators.

Showering has been considered to be a mode of transmission for nosocomial Legionnaires' disease, based on two retrospective studies [28,29], but all prospective studies have failed to validate this hypotheses. In fact, two prospective studies have shown that, not only is showering not a risk factor, but it protects against *Legionella* infection [30,31]. The reason for the paradoxical effect is that patients who take showers are more likely to be ambulatory and at lower risk for acquiring Legionnaires' disease; in contrast, patients who cannot take showers are often bedridden and at higher risk for aspiration. Aerosols generated by hand washing with contaminated water has been suggested as a mode of transmission [32], but there is little hard evidence to support this hypothesis.

Ice machines have been identified as the reservoir and source of some nosocomial infections. Ice-machine contamination may be internal (relating to the components of the machine) or external. *P. aeruginosa*, *Flavobacterium* species, and *Legionella* have resulted from internal contamination [33–35]. Contamination of the external machine may occur because of patient use. One outbreak of cryptosporidiosis was traced to an ice machine contaminated by an incontinent, psychotic patient [36]. Although ice machines are cold-water outlets, several design features provide optimal conditions for microbial growth and formation of biofilm. The cold water passes through small-lumen, flexible tubing that is positioned close to the con-

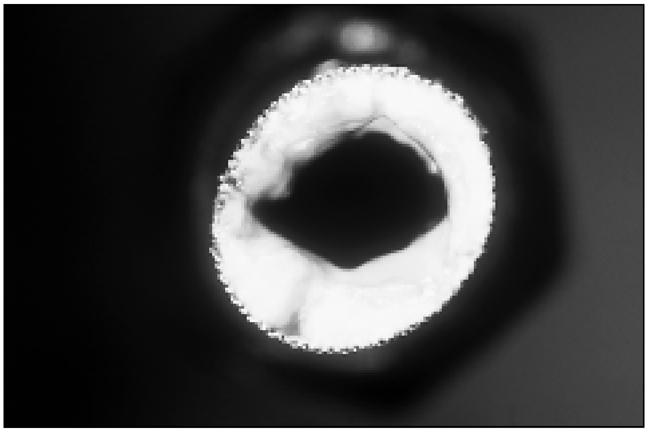

**Figure 1.** Legionella and other bacteria survive and multiply within biofilms. This biofilm formed within a small lumen flexible pipe from a hospital ice machine.

denser/compressor. The heat from the condenser/compressor warms the cold, stagnant water sufficiently to allow bacterial growth, which results in accumulation of biofilm in the pipe (Figure 1). This biofilm can be the source of a variety of bacteria, including Legionella. Cases of Legionnaire's disease have been linked to exposure to the organisms via ice [35]. CDC recommendations for cleaning and maintenance of ice machines have been formulated [37].

Microorganisms easily colonize eyewash stations, because their use is infrequent. The American National Standards Institute (ANSI) recommends that eyewash stations be flushed weekly [38].

In the past, excessive levels of gram-negative bacteria in the dialysate of hemodialyzers were responsible for pyrogenic reactions and bacteremia [39•]. The CDC recommends that the water used to prepare the dialysis fluid be sampled monthly and have less than 200 bacteria per milliliter. Also, dialysate should be sampled monthly and contain less than 2000 colony-forming units per milliliter.

Water baths used for warming or thawing fresh frozen plasma or peritoneal dialysis bottles have been identified as sources of nosocomial infection. Many HCFs have switched to using warm-air cabinets or microwave ovens for warming and thawing these products, to prevent nosocomial infections from waterborne pathogens.

Tub immersion-baths have resulted in waterborne pathogen infections related to whirlpool therapy used for physical therapy and cleaning burns. *Pseudomonas* folliculitis is most frequently seen, but *Legionella* has also been implicated [40]. Adequate disinfection between uses is of utmost importance.

## Transmission

Waterborne pathogens are transmitted via contact, ingestion and aerosolization. Contact transmission may be via HCW's hands to patients, direct patient contact, or equipment contamination (*eg*, rinsing medical equipment with tap water). Ingestion of potable water or ice contaminated with a protozoa such as *Giardia* or *Cryptosporidium* will result in infection, however, these are not common in the hospital setting. Aspiration of a waterborne pathogen, may lead to infection, particularly in an immunocompromised host. Aerosolization was commonly thought to be the mode of transmission of *Legionella*, but new information suggests that aspiration is the predominant mode of transmission [41]. Aspiration may also be a mode of transmission for MAC [13].

## Prevention

Water treatment is designed to prevent most of the major diarrheal illnesses. Chlorine has been used successfully for years. Heterotrophic bacteria in water distribution systems are part of the normal flora and are only opportunistic pathogens. In theory, eliminating waterborne pathogens from the potable water system in healthcare institutions seems simple. But, in reality it is not. Drinking water is not sterile and water pathogens will reproduce in water distribution systems (biofilms, free living cells, cells attached to suspended solids). Growth is influenced by temperature, plumbing disruptions and maintenance. The problem may get worse before it gets better. Water treatment plants have raised the pH of drinking water to reduce lead and copper leaching. However, this increased pH decreases the biocidal action of chlorine. Many pathogens including *Cyrptosporidium* and *Legionella* are relatively resistant to chlorine.

Hand washing with tap water and soap is considered one of the most effective means of preventing nosocomial infections. However, recent outbreak reports suggest that gram negative bacilli may be transmitted via healthcare worker hands to the patient after washing or contact with a contaminated water source [1,3,4]. Waterless bathing and hand washing products are being used in areas where high-risk patients are hospitalized.

Restriction of tap water and ice consumption by immunosuppressed populations has been applied to recipients of organ transplants. Some transplant programs recommend that the patient not consume potable water without first bringing the water to a rolling boil and while hospitalized the patients consume polar water.

Targeted disinfection of the water distribution system has been successful in the control of *Legionella*, particularly copper silver ionization systems [21]. Maintenance of water distribution systems have been commonly recommended by various consultants and authorities for prevention of waterborne infections, especially in hospital-acquired Legionnaires' disease. Unfortunately, the evidence to support this reasonable approach has been lacking. In fact, several studies have shown that hospitals having superior maintenance programs were no more likely to be free of hospital-acquired Legionnaires' disease than those hospitals which did not have such programs.

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