Editorial

Water as a Reservoir of Nosocomial Pathogens

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Understanding the means of acquisition, sources, and reservoirs of nosocomial pathogens is crucial for developing methods to reduce the incidence of nosocomial infections. The article in this issue by Graman et al[1] highlights the continued importance of the environment, especially water sources, as a reservoir for nosocomial pathogens. Important water reservoirs in the hospital include potable water, sinks, faucet aerators, showers, tub immersion, toilets, dialysis water, ice and ice machines, water baths, flower vases, eyewash stations, and dental-unit water stations (Table). This editorial will review water as an important reservoir of nosocomial pathogens, with a focus on methods for prevention and control.

POTABLE WATER

Several noncoliform bacteria can replicate in relatively pure water, including *Pseudomonas aeruginosa*, *Burkholderia cepacia, Serratia marcescens, Acinetobacter calcoaceticus, Flavobacterium meningosepticum, Aeromonas hydrophila,* and certain nontuberculous mycobacteria.[2,3] These organisms may be present in drinking water that has acceptable levels of coliform bacteria (ie, <1 coliform bacterium/100 mL). Reports that gram-negative bacilli may be isolated in large numbers from water-related sources raise concerns that these pathogens may, on occasion, be sources of nosocomial infections.

Potable water has been described as a reservoir in several outbreaks. Most commonly, semicritical equipment has been rinsed with potable water, resulting in contamination of the equipment and subsequent nosocomial infections. Outbreaks have involved tracheal suction tubing contaminated with *Pseudomonas paucimobilis,*[4] otologic equipment contaminated with *Mycobacterium chelonae*,[5,6] material used for discectomies contaminated with *Mycobacterium xenopi*,[7] and endoscopic equipment contaminated with *P aeruginosa.*[8] Rinsing of burn patients with tap water as first aid when entering the hospital has led to serious wound infection and sepsis with *P aeruginosa*.[9]

Nontuberculous mycobacteria have been involved in several outbreaks in addition to those noted above. Costrini and coworkers have described 19 cases of nosocomial pulmonary disease due to *M xenopi,* which was isolated from several hot-water generators and water taps in hospital wards.[10] Two outbreaks of *M chelonae* infections have been reported in patients receiving hemodialysis with reprocessed dialyzers. In both cases, *M chelonae* was isolated from the clinic water supply.[11,12] Because atypical mycobacteria are relatively resistant to agents used for disinfection, it is not surprising that inadequately disinfected equipment that has been in contact with potable water could serve as a source for infection with these pathogens. *Mycobacterium avium* acquisition in human immunodeficiency virus (HIV)-infected

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TABLE
WATER AS A RESERVOIR OF NOSOCOMIAL PATHOGENS

Reservoir	Associated Pathogen(s)	Transmission	Importance*	Prevention and Control
Potable water	*Pseudomonas, Mycobacteria, Legionella*	Contact	Moderate	Follow public health guidelines
Sinks	*Pseudomonas*	Contact, droplet	Low	Use separate sinks for handwashing and disposal of contaminated fluids
Faucet aerators	*Pseudomonas*	Contact, droplet	Low	No precautions necessary at present
Showers	*Legionella*	Inhalation	Low	Prohibit use in immunocompromised patients
Ice and ice machines	*Legionella, Enterobacter, Pseudomonas, Salmonella, Cryptosporidia*	Ingestion, contact	Moderate	Periodic cleaning; use automatic dispenser (ie, avoid open chest storage compartments in patient areas)
Eyewash stations	*Pseudomonas, Legionella, Ameba*	Contact	Low	Have available sterile water for eye flush or weekly (or monthly) flush eyewash stations
Dental-unit water systems	*Pseudomonas, Legionella, Sphingomonas, Acinetobacter*	Contact	Low	Clean water systems
Dialysis water	Gram-negative bacilli	Contact	Moderate	Follow guidelines: dialysate ≤2,000 organisms/mL; water ≤200 organisms/mL
Water baths	*Pseudomonas, Acinetobacter*	Contact	Moderate	Add germicide to water bath or use plastic overwrap of the transfused product
Ice baths for thermodilution catheters	*Ewingella, Staphylococcus*	Contact	Low	Use sterile water
Tub immersion	*Pseudomonas*	Contact	Moderate	Drain and disinfect tub after each use; consider adding germicide to water
Toilets	Gram-negative bacilli	—	Minimum	Utilize good handwashing
Flowers	Gram-negative bacilli, *Aspergillus*	—	Minimum	Prudent to avoid in intensive-care unit and rooms of immunocompromised patients

* High: multiple, well-described outbreaks due to this reservoir; moderate: occasional well-described outbreaks; low: rare, well-described outbreaks; minimum: actual infection not demonstrated.

persons has been linked by molecular analysis to contamination of a hospital water system.[13]

Nosocomial acquisition of *Legionella pneumophila*[14-18] and *Legionella bozemanii*[19] has been linked to contamination of hospital water supplies, and, more recently, the association has been strengthened by use of molecular epidemiological typing methods (eg, DNA fingerprinting by pulsed-field gel electrophoresis) of clinical and environmental strains.[15,18,20-22] *Legionella* can be isolated from more than 50% of the potable water supplies and more than 10% of the distilled water supplies in hospitals.[23] The subject of *Legionella* in hospitals[24] and disinfection of water distribution systems for *Legionella*[25] has been reviewed.

SINKS

A number of reports have demonstrated the presence of gram-negative bacteria in hospital sinks, but patients rarely seem to acquire nosocomial pathogens from this source.[26-29] The ability of gram-negative bacilli to survive wet environments for long periods of time (>250 days) helps to explain their common occurrence in sink drains.[30] Not surprisingly, many of these bacteria isolated from sinks possess resistance to antibiotics such as the aminoglycosides.[30,31]

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Several investigators have suggested that gram-negative bacteria can pass to patients by employees' hands contaminated during handwashing, presumably by splashing of water droplets from the sink basin to hands. This statement is based on several studies that have isolated pathogens colonizing or infecting patients from handwashing sinks.[32-38] For example, Doring et al demonstrated that healthcare workers could develop at least transient hand colonization with *P aeruginosa* strains found in the hospital sinks.[39,40]

Although organisms may pass to patients from employees through handwashing at a contaminated sink, this route does not seem to be an important factor in endemic nosocomial infections. If epidemic spread of gram-negative bacteria from sinks is suspected, control procedures that eliminate the sink as a reservoir should be used.[32,33]

FAUCET AERATORS AND SHOWERS

The faucet aerator has been identified as a reservoir and possible source of infection within the hospital.[41-44] The most convincing evidence that faucet aerators may be reservoirs of nosocomial pathogens is provided by Fierer and coworkers, who used pyocin typing to demonstrate that premature infants became infected with *P aeruginosa* from delivery room resuscitation equipment that was contaminated by a faucet aerator.[42] The importance of faucet aerators as reservoirs for nosocomial pathogens is unknown, but the permanent removal of all aerators and screens from faucets or the disinfection of faucet aerators on a routine basis seems unwarranted at present.

Contaminated hand-held shower heads have been linked to an outbreak of puerperal endometritis with group A streptococci.[45] *L pneumophila* also has been isolated from shower heads.[46] Despite sterilization of the shower heads with ethylene oxide, rapid recontamination occurred, suggesting that the potable water also was contaminated.

ICE AND ICE MACHINES

Contaminated ice and ice machines occasionally may be a source for nosocomial infections. Hutchings and Wheeler, in 1903, reported an epidemic of *Salmonella typhi* among hospital staff because of the use of ice obtained from a fecally contaminated river.[47] During the last 25 years, several reports have linked nosocomial epidemics or pseudoepidemics to contaminated ice or ice machines. Newson reported an outbreak of serious pulmonary and wound infections caused by *Enterobacter cloacae* and *P aeruginosa* traced to an ice machine with bad plumbing.[48] Patients were presumed to have acquired the epidemic pathogens by sucking on ice or ingesting iced drinks. Ravn et al reported an outbreak of cryptosporidiosis, involving both HIV-positive and -negative subjects, that was traced to an ice machine contaminated by an incontinent, psychotic patient.[49] Stamm and coworkers reported an outbreak of *Flavobacterium* sepsis in 14 patients that was traced to the use of nonsterile ice. Investigation revealed that the ice machine in the intensive-care unit served as the reservoir for the epidemic pathogen.[50] An outbreak of *Mycobacterium fortuitum* colonization[51] and pseudo-epidemics of *M fortuitum*[52] and *Mycobacterium gordonae*[53] also have been linked to contaminated ice machines acting as a reservoir for these organisms. Despite these reports, a survey of ice machines found few organisms of significance colonizing the ice or the machines.[54]

L pneumophila may colonize several water sources. Stout et al discovered that the cold-water dispensers of 8 of 14 ice machines yielded *L pneumophila*.[55] Positivity of these sites was linked to the incoming cold-water supply by recovering *L pneumophila* from the cold-water storage tank, which was supplied directly by the incoming municipal water line. Although no epidemiological link to disease was made, the hospital eliminated the cold-water dispenser from ice machines. However, more recently, Bangsborg et al linked nosocomial legionellosis in two heart-lung transplant patients to a contaminated ice machine,[56] and Gahrn-Hansen linked nosocomial legionellosis in a renal transplant unit to contamination in the ice machine and shower water.[57] The article in this issue by Graman and colleagues again emphasizes the ability of *Legionella* to be present in multiple water sources including ice machines.[1]

Because meaningful microbial standards for ice, ice-making machines, and ice storage compartments do not exist, routine cultures of ice machines are not recommended. The Centers for Disease Control and Prevention (CDC), however, has published a set of recommendations designed to minimize ice- and ice-machine–associated infections.[58] A regular program of disinfection of ice machines is included in these recommendations. More recently, Burnett and colleagues have provided guidelines of the maintenance of ice machines.[54]

EYEWASH STATIONS

Stationary and portable eyewash stations, which may be unused for months or years, represent a reservoir for potential pathogens. An analysis of 40 eyewash stations revealed the following contamination rates: heterotropic bacteria (majority of isolates, *Pseudomonas* species), 95%; *Legionella* species, 7.5%;

amoebae (eg, *Hartmannella*), 47.5%; and fungi, 42.5%.[59] This high contamination rate raises concerns that serious eye infections could result if such eyewash stations were used to flush injured eyes. Because the source water may stand in the incoming pipes at room temperature for a year or more, it has been recommended by the American National Standards Institute (Z358-1981) that eyewash stations be flushed weekly. Ideally, eyes should be flushed with unused bottles of sterile water or other solutions. However, a disadvantage of the eyewash bottles is the small volume. When a chemical spill to the eyes occurs, copious amounts of water are required to flush the injured eye.[59]

DENTAL-UNIT WATER SYSTEMS

Dental units are equipped with plastic tubing to bring water to the different dental handpieces (the air-water syringe, the ultrasonic scaler, and the high-speed handpiece). Potable water normally supplies these dental units. With use, the water lines in the dental units may become contaminated heavily with microorganisms. One study reported that all dental units were contaminated with at least 5 logs of bacteria, most commonly *Sphingomonas, Pseudomonas, Acinetobacter,* and *Methylobacterium*.[60] *L pneumophila,* other *Legionella* species,[61] and nontuberculous mycobacteria[62] have been recovered from dental-unit water supplies. Although the clinical significance is not documented fully,[61,63] it has been reported that pseudomonal infection of immunocompromised patients[63] and legionellosis in a California dentist[61] have resulted from use of a contaminated dental-unit water system. Control measures for purging or disinfecting the system include water flushes (a 2-minute purge with water reduces counts on average by one third), flush with a disinfectant solution, or use of a "clean-water system" (a system that feeds sterile water into the dental unit). However, there are concerns that flushes with water still result in bacterial levels of greater than 3 logs,[64] while disinfectant flushes may not be successful in eradicating bacteria contained in biofilms. The clean-water units must be disinfected weekly, or they become contaminated with large numbers of microorganisms. Further studies are necessary to determine the infection risk from dental-unit water systems and the effectiveness of control measures designed to reduce the risk.[65]

DIALYSIS WATER

It was demonstrated in the 1970s that excessive levels of gram-negative bacteria in the dialysate of hemodialyzers were responsible for pyrogenic reactions or bacteremia. This hazard is caused either by the organism gaining entrance to the blood from the dialysate or by endotoxins from gram-negative bacteria associated with the water and dialysate passing intact through membranes and causing pyrogenic reactions. In one study by Favero et al, the attack rates of pyrogenic reactions were related directly to the levels of gram-negative bacteria in the dialysate.[66,67] It also has been demonstrated that certain types of bacteria, especially the water bacteria, have the capability of surviving and multiplying in distilled, deionized, reverse-osmosis, and softened water, all of which have been used to supply water for hemodialysis.[67] Based on these data, it has been suggested by the CDC that the water used to prepare dialysis fluid should be sampled monthly and that the supply water should have less than 200 bacteria/mL. The dialysate also should be sampled monthly and should contain less than 2,000 bacteria/mL.[68,69] Factors that influence microbial contamination of hemodialyzers and infection control measures have been described elsewhere.[67]

WATER BATHS

Several outbreaks of serious nosocomial infections (eg, endocarditis, bacteremia, peritonitis) with *Pseudomonas* or *Acinetobacter* have been traced to contaminated 37ºC water baths that were used to thaw fresh plasma[70] or cyroprecipitate,[71] or used to warm bottles of peritoneal dialysate before use.[72,73] In each outbreak, the water bath was contaminated heavily with the disease-causing organism, and contamination of the infusate occurred when the fluid was being prepared for administration.

In view of these outbreaks, it would be prudent to develop policies for the routine cleaning, disinfection, and changing of water in water baths used to thaw or warm blood products. After cleaning, the bath should be filled with water to which a germicide has been added. In general, we do not advocate routine microbiological sampling of the hospital environment, but we do sample quarterly the water baths used for thawing fresh-frozen plasma or for warming whole blood. Alternatively, the surfaces of these blood products can be kept dry if they are enclosed in an impermeable plastic overwrap. Equally effective but more time-consuming methods to prevent transmission by contaminated water baths have been proposed.[70,72]

The problem of contaminated water baths and dialysis bottles simply may be eliminated by using warm-air cabinets or a microwave to preheat the dialysis solution before use.

ICE BATHS FOR THERMODILUTION CARDIAC OUTPUTS

Thermodilution is the most common method of measuring cardiac output. Until recently, the most frequently used technique involved the injection of cooled saline. Often, cooling was accomplished by placing individual syringes or bottles of saline in ice baths derived from mixing nonsterile ice with water, which led to several outbreaks ascribed to contamination of the ice-water baths.[74,75] Currently, cardiac output generally is measured by injecting room-temperature saline.

TUB IMMERSION

Tub immersion is used in the hospital as an aid in physical therapy, for cleaning burn wounds and bathing babies, and, until recently, was required for kidney lithotripsy. Skin infections related to water immersion have been recognized for many years.[76] The majority of these infections have been *P aeruginosa* folliculitis and have been associated with contaminated whirlpools or hot tubs.[77] The clinical course of these infections usually is mild, and they characteristically resolve without specific therapy.

Tub immersion of hospitalized patients could lead to infection via cross-transmission, transmission from an environmental reservoir, or autotransmission (eg, infection of the wound by fecal flora). Frequently, immersion of hospitalized patients will contaminate the tub environment, including the tub water, drains, agitators, floors, and walls.[78-81] Inadequate disinfection of immersion tanks has led to an outbreak of *P aeruginosa* infections caused by cross-transmission.[82] *Citrobacter freundii* cellulitis also has been reported after hot-tub immersion.[83] Contamination of a baby bath was linked to an outbreak of *Clostridium difficile* colonization among neonates.[84] Prevention of nosocomial transmission of nosocomial infections requires adherence to strict disinfection protocols.[85,86] In addition, the epidural catheter used for anesthesia in patients undergoing lithotripsy should be covered with a transparent occlusive dressing.[87]

HOSPITAL TOILETS

The microbiology of hospital toilets has been investigated carefully by Newsom, who obtained cultures of the air, water, and surfaces of hospital toilets and the bacteria in the air or splashes after toilet flushing.[88] The frequency and level of contamination of the air, water, and surface of hospital toilets by fecal bacteria was surprisingly low at 27% (<10 colony-forming units [CFU]/mL), 39% (<2,500 CFU/mL), and 6% (≤4 CFU/mL), respectively. The likelihood of generating a bacterial aerosol was studied in artificial flushing experiments; at least 10^{10} bacteria/100 mL of toilet water were required to produce an aerosol. The bacterial counts in toilet water were reduced 100-fold by a single flush.

The ability of enteric bacteria to survive desiccation also was observed. Drops of feces allowed to dry on a toilet seat were nearly free of *Escherichia coli* in 2 hours. *Shigella* and *Salmonella* in feces died out in 4 and 12 days, respectively.

In consideration of these data and the numbers of bacteria (at least 10^2 *Shigella* to 10^7 *Salmonella typhi)* that must be ingested to cause human disease in normal hosts, it seems that the hospital toilet is an unlikely source of infection. This may not be true if the surfaces are coated heavily with feces, as could happen in hospitals for mentally impaired patients, pediatric wards, daycare centers for children, or with neurologically impaired adults. Cross-transmission of *C difficile* colitis was reported after two adult patients shared a commode chair.[89] A pseudo-epidemic of multidrug-resistant *P aeruginosa* among hematologic patients occurred after a healthcare worker obtained stool samples from the toilet following defecation.[90] The flushing water and toilet brush were found to be contaminated with the suspected epidemic pathogen.

The care of the hospital toilet should be restricted to maintaining the surfaces clean with a disinfection solution and cleaning the bowl with a scouring powder in conjunction with a brush. There is no reason to pour disinfectants into the bowl. As always, good handwashing practices would remove any transient microbial flora from the hands and eliminate any risk of cross-infection.

FLOWERS

Concern has been expressed that cut flowers may represent a reservoir of pathogenic bacteria, even though no actual outbreaks of nosocomial infections have been linked to cut flowers as a source.[91] Cultures of tap water made 72 hours after the water was placed in vases yielded approximately 10^7 to 10^{10} bacteria/mL.[91-93] Bacteria isolated from vases located on hospital floors have included *Acinetobacter* species, *Klebsiella* species, *Enterobacter* species, *P aeruginosa, B cepacia, Pseudomonas fluorescens, Pseudomonas putida, A hydrophilia, S marcescens,* and *Flavobacterium*.[93-96] Studies have failed, however, to link pathogens isolated from flower vases or potted plants with pathogens isolated from nearby patients.[94,97]

The addition of the following antibacterial agents to the vase water has been shown to lead to a significant reduction of bacteria without injuring the flowers: 10 mL of 1% hypochlorite,[91] 0.01% to 0.02% chlorhexidine,[98,99] and 30-60 mL of 3% hydrogen peroxide.[92,94] In spite of these data, it seems prudent to prohibit fresh flowers in the rooms of immunocompromised and intensive-care–unit patients. One publication recommended that the following procedures should be followed for handling flowers[95]: (1) handling of flowers should be designated to support staff with no patient contact or, when this is not feasible, gloves should be worn for flower handling; (2) handwashing should follow any contact with plant material; (3) vase water should be changed at least every 2 days; (4) vase water should be disposed of into clinical sinks, not handwashing sinks; and (5) vases should be disinfected after use. In addition, an antibacterial agent could be added to the vase water.

OTHER WATER SOURCES

Improperly maintained devices for producing distilled water or containers used for storing distilled water have led to outbreaks with *E cloacae*[100] and *B cepacia*.[101] An outbreak of *Salmonella urbana* infection in a neonatal nursery was linked to use of a contaminated wash basin.[102] An outbreak of *B cepacia* bacteremia was associated with a contaminated water reservoir of the intraaortic balloon pump.[103]

Recently, Fridkin and colleagues linked four cases of postoperative endophthalmitis with *Acremonium kiliense* to contaminated ventilation-system humidifier water.[104] Blue and coworkers linked an outbreak of gastrointestinal illness with neurologic sequelae to drinking from an institutional water cooler.[105]

Rees and Allen have described a case of hospital-acquired infection due to *Acinetobacter baumanii* in a burn patient after exposure to contaminated holy water.[106]

CONCLUSION

These reports demonstrate the continued importance of water as a reservoir of nosocomial pathogens. Our infection control practices should be directed to interrupt the transmission of these pathogens to the patient.

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Calendar

November 6-7, 1997. The Eastern Pennsylvania Branch of the American Society for Microbiology will present its annual symposium at the Adam's Mark Hotel in Philadelphia, Pennsylvania. The topic is "Chronic Infectious Diseases: Mechanisms, Diagnosis, and Treatment." Some of the topics to be considered include, but are not limited to, mechanisms of autoimmunity, mechanisms of intracellular parasitism, mechanisms of viral latency, osteomyelitis, endocarditis, cystic fibrosis, *Helicobacter pylori,* Creutzfeldt-Jakob disease, *Chlamydia* with possible links to atherogenesis, Lyme disease, Kaposi's sarcoma, and novel therapeutic and diagnostic approaches to chronic infectious disease. Submission of posters is encouraged.

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