The Hospital Water Supply as a Source of Nosocomial Infections

A Plea for Action

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Background: Microbiologically contaminated drinking water is a cause of community-acquired infection, and guidelines for prevention of such infections have been established. Microbes in hospital water can also cause nosocomial infection, yet guidelines for preventing such infections do not exist. The purpose of this review is to assess the magnitude of the problem caused by waterborne nosocomial infections and to plea for immediate action for their prevention.

Methods: We conducted a MEDLINE search of the literature published between January 1, 1966, and December 31, 2001.

Study Selection and Data Extraction: Investigations in which microorganisms (other than Legionella species) caused waterborne nosocomial infections and public health agency recommendations for drinking water.

Results: Forty-three outbreaks of waterborne nosocomial infections have been reported, and an estimated 1400 deaths occur each year in the United States as a result of waterborne nosocomial pneumonias caused by Pseudomonas aeruginosa alone. Despite the availability of effective control measures, no clear guidelines exist for the prevention of these infections. By contrast, guidelines for the prevention of community-acquired waterborne infections are now routinely used. Hospitals caring for patients at high risk for infection do not enforce the standards of water quality recommended by US and United Kingdom public health agencies for the patients’ community counterparts.

Conclusion: Because of the seriousness of these nosocomial waterborne infections and the availability, low cost, and proven effectiveness of sterile water, we recommend that hospitalized patients at high risk for infection avoid exposure to hospital water and use sterile water instead.

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Each year in the United States, more than 2 million nosocomial infections occur in as many as 10% of all hospitalized patients, causing significant morbidity, mortality, and financial burden.1-3 In addition, the use of antibiotics to treat these infections leads to increased resistance.4-5 These infections tend to occur more commonly in immunocompromised patients.6 Although numerous hospital sources cause nosocomial outbreaks, perhaps the most overlooked, important, and controllable source of nosocomial pathogens is hospital water.7-9

The ability of microbes to survive in hospital water tanks was described more than 30 years ago,10 and numerous studies11-52 have identified water as a source of nosocomial infection. These organisms can acquire and subsequently transfer antimicrobial resistance53 and can produce toxins, as demonstrated in a recent catastrophic outbreak secondary to contamination of hemodialysis water (110 cases and 43 deaths).54 Despite the large number of waterborne nosocomial outbreaks,11-52 no hospital guidelines exist for their prevention.

This article describes the extent of waterborne nosocomial infections and their mode of transmission and recommends guidelines for their prevention.

RESULTS

TYPES OF PATHOGENS AND INFECTIONS

Legionella pneumophila

Of all the water-related pathogens, L. pneumophila is most likely to be recognized by health care workers as a cause of nosocomial infection. However, the acquisition of L. pneumophila infection in the hospital setting is similar to that of other water organisms. The agents of legionellosis and those...
of other nosocomial waterborne infections share remarkable similarities, including (1) their presence and amplification in water reservoirs, (2) a strong association with water biofilms, (3) growth requirements (optimal growth at 25°C–45°C, with growth inhibition at higher and lower temperatures), (4) a link between infection with these agents and construction activity, and (5) mode of transmission (aerosolization, ingestion, and contact). Similar to Legionella species, these bacteria (including Pseudomonas aeruginosa) have also been shown to exist not only in biofilms but also inside free-living amoebae. These amoebae harbor the bacteria inside their cysts, giving them a microhabitat and protecting them from disinfectants.

Although recommendations for preventing legionellosis have become standard knowledge in medical textbooks, nosocomial waterborne infections by other microbes have been largely ignored despite their high morbidity and mortality rates.

**Other Waterborne Pathogens**

**Bacteria.** Nosocomial infections caused by waterborne bacteria have been associated with serious morbidity and even mortality and include bacteremias, tracheobronchitis, pneumonias, sinusitis, urinary tract infections, meningitis, wound infections, peritonitis, ocular infections, and others. Specifically, P aeruginosa can persist in hospital water for extended periods and can cause nosocomial outbreaks. Stenotrophomonas maltophilia is a multidrug-resistant organism that has been implicated in nosocomial waterborne infections. Other bacteria associated with waterborne nosocomial infections include species of Aeromonas, Acinetobacter, Burkholderia, Enterobacter, Flavobacterium, other Pseudomonas, Serratia, and others. Overall, these nosocomial waterborne infections were caused by bacteria resistant to at least 2 classes of antimicrobial agents in 76% of the 17 outbreaks for which susceptibility testing was performed (Table 1 and Table 2).

**Mycobacteria.** Pathogenic mycobacteria have been isolated from hospital water, can persist in water systems over several years, and have been implicated in serious nosocomial outbreaks.

**Fungi.** Nosocomial aspergillosis continues to occur despite air filtration, thus suggesting that there may be other hospital sources of spores. Fungi can inhabit water distribution systems, including those of hospitals, and may cause nosocomial infection. The water system of one hospital in Houston, Tex, harbored Fusarium species, causing infections among its patients. Other opportunistic molds, including Aspergillus species, have been recovered from the same hospital and from 2 other hospital water systems in Little Rock, Ark. Exophiala jeanselmei was responsible for 23 life-threatening nosocomial infections. Additional evidence that the opportunistic molds are waterborne comes from the serious infections caused by Aspergillus species and Pseudallescheria boydii after near-drowning incidents in otherwise healthy individuals. Pneumocystis carinii DNA has been recovered from water. Whether P carinii exists within hospital water distribution systems needs to be determined in light of the study results suggesting nosocomial transmission of pneumocystosis.

**Parasites.** Outbreaks of toxoplasmosis have been traced to contaminated water, thus, Toxoplasma gondii could also potentially cause nosocomial waterborne infections.

**Viruses.** Several pathogenic viruses can also be recovered from water supplies, although nosocomial waterborne infections with these agents have not been reported.

**Outbreaks Supported by Quality Evidence, Including Molecular Relatedness Studies**

Some of the older studies included in our review did not use the appropriate epidemiologic methods or the modern molecular relatedness tools and relied on weakly discriminatory methods for strain typing, such as serotyping and antibiotic susceptibility patterns (Table 2). However, 29 recent studies present solid evidence, both epidemiologic and molecular, incriminating the hospital water system as the source of serious waterborne nosocomial infections (Table 1).

The outbreaks mentioned herein probably represent only a subset of the total number of waterborne nosocomial infections because these outbreaks are limited to reports in which the pathogen involved was recovered from the water supply. However, the water supply could also have been the reservoir for pathogens in other out-

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References 11-15, 17-21, 23-26, 28, 32, 37, 41, 42, 44-52.

References 16, 22, 27, 29-31, 33-36, 38-40, 43.
breaks in which cultures of the water supply were not obtained or did not yield the pathogen because of inadequate sampling or variations of the pathogen's load in the water system (related to external factors such as status of the plumbing system and recent obstruction of flow). In such settings, hospital water may have contaminated environmental surfaces (eg, sinks, drains, and whirlpool baths), medical equipment (eg, by rinsing tube feed bags, endoscopes, respiratory equipment, etc, with tap water), or health care providers, leading ultimately to patient exposure \(^7,72-119\) (Figure). Thus, the environmental surfaces, medical equipment, or health care workers may seem to be the pathogen's source; however, hospital water was the primary reservoir but was not tested or the organism was not recovered because of the variables mentioned previously. Forty-nine reported outbreaks in which such a scenario could have occurred include infections with the following pathogens: Acinetobacter baumannii, Acinetobacter calcoaceticus, Alcaligenes faecalis, Alcaligenes xylosoxidans, Burkholderia cepacia, Enterobacter cloacae, Ewingella americana, Flavobacterium species, group A streptococci, P aeruginosa, Serratia marcescens, S maltophilia, Pseudomonas thomassii, Pseudomonas species, Rahnella aquatilis, Salmonella urbana, vancomycin-resistant enterococci, Mycobacterium chelonae, Candida tropicalis, Aspergillus niger, Acremonium kiliense, and Cryptosporidium species. However, because of the difficulty in identifying the original source of the infection in such reports, we elected to exclude these outbreaks and to limit our review to instances in which the hospital water was clearly documented to be the pathogen's reservoir.

Table 1. Nosocomial Infections Related to the Hospital Water Supply (Tap Water and Water Reservoirs Only): Reports With Supporting Molecular Relatedness Studies\(^\ast\)

<table>
<thead>
<tr>
<th>Organism</th>
<th>Source</th>
<th>Site(s) of Infection</th>
<th>Method(s) Used to Link Patient and Environmental Strain</th>
<th>Susceptibility of Organism(^\dagger)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pseudomonas aeruginosa</td>
<td>Trautmann et al,(^\dagger) 2001</td>
<td>Blood, lungs, peritoneum, trachea, urine</td>
<td>AP-PCR</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Bert et al,(^\dagger) 1998</td>
<td>Lung, sinuses, urine</td>
<td>DNA macrorestriction analysis</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Buttery et al,(^\dagger) 1998</td>
<td>Blood, central venous catheter, skin, urine</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Ferroni et al,(^\dagger) 1998</td>
<td>Urine</td>
<td>PFGE</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Ezpeleta et al,(^\dagger) 1998</td>
<td>Blood</td>
<td>ERI-PCR, RAPD</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Burucoa et al,(^\dagger) 1995</td>
<td>Not reported</td>
<td>DNA fingerprinting</td>
<td>Susceptible</td>
</tr>
<tr>
<td></td>
<td>Richard et al,(^\dagger) 1994</td>
<td>Blood, lung, wound</td>
<td>DNA typing, serotyping</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Kolmos et al,(^\dagger) 1993</td>
<td>Blood</td>
<td>Phage typing, serogrouping</td>
<td>Susceptible</td>
</tr>
<tr>
<td></td>
<td>Grundmann et al,(^\dagger) 1993</td>
<td>Blood, CSF, trachea</td>
<td>Gelotyping, serotyping</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Worlitzsch et al,(^\dagger) 1999</td>
<td>Urine</td>
<td>ExoA DNA probe</td>
<td>Not reported</td>
</tr>
<tr>
<td>Stenotrophomonas maltophilia</td>
<td>Weber et al,(^\dagger) 1999</td>
<td>Peritoneum, respiratory tract, skin</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Verweij et al,(^\dagger) 1998</td>
<td>Trachea</td>
<td>RAPD</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Chachaty et al,(^\dagger) 1998</td>
<td>Blood, stools</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Talon et al,(^\dagger) 1994</td>
<td>Blood, stools, throat, urine</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td>Serratia marcescens</td>
<td>Carlyon et al,(^\dagger) 1998</td>
<td>Eye, stools</td>
<td>PFGE</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Pina et al,(^\dagger) 1998</td>
<td>Skin, wound</td>
<td>PFGE, biotyping</td>
<td>Not reported</td>
</tr>
<tr>
<td>Acinetobacter baumannii</td>
<td>Pichard and Goullet,(^\dagger) 1987</td>
<td>Blood</td>
<td>Electrophoretic esterase typing</td>
<td>Not reported</td>
</tr>
<tr>
<td>Aeromonas hydrophila</td>
<td>De Schuijmer et al,(^\dagger) 1998</td>
<td>Blood</td>
<td>AP-PCR</td>
<td>Not reported</td>
</tr>
<tr>
<td>Chryseobacterium species</td>
<td>Kauppinen et al,(^\dagger) 1998</td>
<td>Sputum, skin</td>
<td>RFLP, PFGE, AFLP, PCR</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Verweij et al,(^\dagger) 1998</td>
<td>Trachea</td>
<td>RAPD</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Chachaty et al,(^\dagger) 1998</td>
<td>Blood, stools</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Talon et al,(^\dagger) 1994</td>
<td>Blood, stools, throat, urine</td>
<td>PFGE</td>
<td>Resistant</td>
</tr>
<tr>
<td></td>
<td>Desplaces et al,(^\dagger) 1995</td>
<td>Sputum, skin, wound</td>
<td>PCR-based techniques</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Talon et al,(^\dagger) 1994</td>
<td>Blood, stools, throat, urine</td>
<td>Chromosomal restriction fragment patterns</td>
<td>Susceptible</td>
</tr>
<tr>
<td></td>
<td>Wallace et al,(^\dagger) 1989</td>
<td>Sputum, skin, wound</td>
<td>RFLP, PFGE, AFLP, PCR</td>
<td>Not reported</td>
</tr>
<tr>
<td>Mycobacteria</td>
<td>Wallace et al,(^\dagger) 1989</td>
<td>Sputum, skin, wound</td>
<td>Electrophoresis of enzymes, plasmid profiling</td>
<td>Resistant to doxycycline</td>
</tr>
<tr>
<td>Mycobacterium avium</td>
<td>Von Reyn et al,(^\dagger) 1994</td>
<td>Disseminated</td>
<td>PFGE</td>
<td>Not reported</td>
</tr>
<tr>
<td>Mycobacterium fortuitum</td>
<td>Kaupinen et al,(^\dagger) 1999</td>
<td>Disseminated</td>
<td>AP-PCR</td>
<td>Susceptible</td>
</tr>
<tr>
<td></td>
<td>Hector et al,(^\dagger) 1992</td>
<td>Respiratory tract, wound</td>
<td>PFGE</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Burns et al,(^\dagger) 1991</td>
<td>Sputum</td>
<td>Phenotype analysis, plasmid profiles, PFGE</td>
<td>Partially reported</td>
</tr>
<tr>
<td>Mycobacterium xenopi</td>
<td>Benitez et al,(^\dagger) 1999</td>
<td>Various</td>
<td>PCR-based techniques</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Desplaces et al,(^\dagger) 1995</td>
<td>Spine</td>
<td>Chromosomal restriction fragment patterns</td>
<td>Resistant</td>
</tr>
<tr>
<td>Mycobacterium kansasi</td>
<td>Picard et al,(^\dagger) 1997</td>
<td>Abscess, blood, bone, sputum, stomach, urine</td>
<td>RFLP, PFGE, AFLP, PCR</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Wallace et al,(^\dagger) 1989</td>
<td>Sternal wound infection, prostatic valve</td>
<td>Electrophoresis of enzymes, plasmid profiling</td>
<td>Resistant to doxycycline</td>
</tr>
<tr>
<td>Fungi</td>
<td>Fusarium solani</td>
<td>Anaissie,(^\dagger) 1998</td>
<td>Disseminated</td>
<td>RFLP, RAPD, IR-PCR</td>
</tr>
<tr>
<td>Exophiala jeansiemao</td>
<td>Nucci et al,(^\dagger) 1998</td>
<td>Disseminated</td>
<td>RAPD</td>
<td>Not reported</td>
</tr>
<tr>
<td>Aspergillus fumigatus</td>
<td>Anaissie et al,(^\dagger) 2002</td>
<td>Lungs</td>
<td>PCR, SSDP</td>
<td>Not reported</td>
</tr>
</tbody>
</table>

\(^*\)AP-PCR indicates arbitrarily primed polymerase chain reaction; PFGE, pulse-finger gel electrophoresis; ERI-PCR, enterobacterial repetitive intergenic consensus sequence PCR; RAPD, random amplified polymorphic DNA; CSF, cerebrospinal fluid; ExoA, exotoxin A; RFLP, restriction fragment length polymorphism; AFLP, amplified fragment length polymorphism; IR-PCR, inter-repeat PCR; and SSDP, sequence-specific DNA primer analysis.

\(^\dagger\)Resistant means resistant to 2 or more classes of antibiotics.


Although it may be difficult to accurately measure the magnitude of the problem of nosocomial waterborne infections, an estimation of the minimal incidence of these infections and their attributable consequences is possible by focusing on pneumonia with waterborne pathogens. Although it may be difficult to accurately measure the magnitude of the problem of nosocomial waterborne infections, an estimation of the minimal incidence of these infections and their attributable consequences is possible by focusing on pneumonia with waterborne pathogens. Although it may be difficult to accurately measure the magnitude of the problem of nosocomial waterborne infections, an estimation of the minimal incidence of these infections and their attributable consequences is possible by focusing on pneumonia with waterborne pathogens.

### MAGNITUDE OF THE PROBLEM

The primary cause of diminished water quality is the buildup of biofilm and the corrosion of distribution lines and tank surfaces resulting from poor design or aging of distribution systems and water stagnation. Increased water demand during summer or when construction activity increases flow through stagnant pipelines, dislodging organisms from biofilms and releasing them into the water supply. The effect of waterborne pathogens in the hospital setting may be enormous.

### MODE OF TRANSMISSION TO PATIENTS

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### Table 2. Nosocomial Infections Related to the Hospital Water Supply (Tap Water and Water Reservoirs Only): Reports Without Supporting Molecular Relatedness Studies

<table>
<thead>
<tr>
<th>Organism</th>
<th>Source</th>
<th>Site(s) of Infection</th>
<th>Method(s) Used to Link Patient and Environmental Strain</th>
<th>Susceptibility of Organism*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>Rudnick et al.(^{38}) 1996</td>
<td>Blood</td>
<td>Serotyping</td>
<td>Not reported</td>
</tr>
<tr>
<td></td>
<td>Martino et al.(^{28}) 1985</td>
<td>Blood</td>
<td>Serotyping</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>Stenotrophomonas maltophilia</em></td>
<td>Khardori et al.(^{27}) 1990</td>
<td>Blood, lungs, urine, wound</td>
<td>Serotyping, antibiogram</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>Pseudomonas multivariana</em> (Burkholderia cepacia)</td>
<td>Basset et al.(^{33}) 1970</td>
<td>Wound</td>
<td>Serotyping, antibiogram</td>
<td>Not reported</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>Gilchrist et al.(^{39}) 1986</td>
<td>Blood, nasopharynx</td>
<td>Antibiogram</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>Pseudomonas aeruginosa</em></td>
<td>Crane et al.(^{31}) 1981</td>
<td>Sputum, urine</td>
<td>Temporal association</td>
<td>Not reported</td>
</tr>
<tr>
<td><em>Acinetobacter baumannii</em></td>
<td>Ritter et al.(^{32}) 1993</td>
<td>Catheter, trachea, stomach, umbilicus</td>
<td>Biochemical profile, antibiogram</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>Enterobacter cloacae</em></td>
<td>Banjeree et al.(^{34}) 1996</td>
<td>Blood, respiratory tract, urine, wound</td>
<td>Antibiogram</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>Flavobacterium meningosepticum</em></td>
<td>Pokrywka et al.(^{35}) 1993</td>
<td>Blood, respiratory tract</td>
<td>Temporal association</td>
<td>Susceptible</td>
</tr>
<tr>
<td><em>Campylobacter jejuni</em></td>
<td>Rautelin et al.(^{36}) 1990</td>
<td>Stools</td>
<td>Temporal association</td>
<td>Susceptible</td>
</tr>
<tr>
<td><em>Serratia marcescens, Klebsiella oxytoca, Klebsiella pneumoniae</em></td>
<td>Pegues et al.(^{37}) 1994</td>
<td>Blood, meninges</td>
<td>Serotyping, temporal association</td>
<td>Resistant</td>
</tr>
<tr>
<td><em>P aeruginosa, Pseudomonas vesciculare, S maltophilia</em></td>
<td>Vanholder et al.(^{38}) 1990</td>
<td>Blood</td>
<td>Temporal association</td>
<td>Not reported</td>
</tr>
<tr>
<td><strong>Mycobacteria</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Mycobacterium chelonae subsp abscessus</em></td>
<td>Soto et al.(^{39}) 1991</td>
<td>Nasal cellulitis</td>
<td>Temporal association</td>
<td>Susceptible</td>
</tr>
</tbody>
</table>

*Resistant means resistant to 2 or more classes of antibiotics.

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cet tap water, and showers. Even small quantities of organisms in water can cause infection. A single exposure to 200 mL of water could result in 6000 infections per year in a city the size of New York, and a single exposure to 200 mL of water may result in serious mold infections.

Only one of the studies evaluated the hospital water supply for the presence of this pathogen and did not find it. The absence of this organism in the water supply does not by itself rule out the fact that the system was contaminated. Potential explanations include the limited number of samples obtained in the study and the contamination of a segment of the system only. It is possible, however, that contamination of the faucets by patients may have occurred.

**CURRENT PREVENTIVE GUIDELINES**

**Community Guidelines for the Prevention of Waterborne Infections**

After the 1993 outbreak of cryptosporidiosis in Milwaukee, Wis (403000 infections, 4400 hospitalizations, and 104 deaths), several public health agencies issued recommendations that targeted immunodepressed patients. These recommendations stated that such patients should be provided information about measures to ensure their drinking water is safe and should only drink water that is bottled sterile, submicron filtered or boiled, in outbreak settings.

**Hospital Guidelines for the Prevention of Legionellosis and Aspergillosis**

The Centers for Disease Control and Prevention (CDC), Atlanta, Ga, developed recommendations for the prevention of nosocomial pneumonia and legionellosis that include routine maintenance of the hospital water supply system and consideration for the use of sterile water in immunodepressed patients. For the prevention of hospital-acquired aspergillosis, the CDC recommends the following: (1) minimizing exposure of high-risk patients to potential sources of Aspergillus species and to activities that may aerosolize Aspergillus and other fungi, and (2) eliminating the source of aspergilli. Because opportunistic molds can inhabit hospital water systems and aerosolize after water activities, these CDC recommendations imply that water precautions need to be introduced in hospitals caring for patients at risk for opportunistic mycoses. Because the data on the potential waterborne nature of nosocomial aspergillosis were not available at the time of these recommendations, specific recommendations to avoid water exposure to prevent aspergillosis were not offered.

Finally, when the hospital water of institutions caring for stem cell transplant recipients is colonized with Legionella species, the CDC recommends the use of sterile water for drinking, brushing teeth, flushing nasogastric tubes, and rinsing nebulization devices and other semicritical respiratory care equipment. The CDC also recommends avoiding showering (using sponge baths instead) and exposure to faucet water and prompt cleaning and repair of water leaks to prevent mold proliferation in patient care areas (Table 3).
Table 4. Effective Measures Used to Terminate Outbreaks of Nosocomial Waterborne Infections

<table>
<thead>
<tr>
<th>Method</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair of water systems</td>
<td>Baneree et al., 1996</td>
</tr>
<tr>
<td>Disinfection of water distribution systems,</td>
<td>Chachaty et al., 1998; Picard and Goullet,</td>
</tr>
<tr>
<td>including tanks</td>
<td>1987; Vanholder et al., 1990; Soto et al.,</td>
</tr>
<tr>
<td>Maintenance program</td>
<td></td>
</tr>
<tr>
<td>Entire water system</td>
<td>Chachaty et al., 1998; Picard and Goullet,</td>
</tr>
<tr>
<td>Monitoring of faucet taps</td>
<td>1987; Vanholder et al., 1990; Soto et al.,</td>
</tr>
<tr>
<td>Avoidance of tap water (for bathing, drinking, and procedures)</td>
<td>Verweij et al., 1998; Chachaty et al., 1998; Picard and Goullet, 1987; Breiman et al., 1990</td>
</tr>
<tr>
<td>Restriction of connection of equipment to water sources until immediately before use</td>
<td>Rudnick et al., 1996; Kolmos et al., 1993</td>
</tr>
</tbody>
</table>

Table 5. Efficacy of Water Disinfection Methods Against Various Pathogens*

<table>
<thead>
<tr>
<th>Method</th>
<th>Legionella</th>
<th>Mycobacteria</th>
<th>Molds</th>
<th>Viruses</th>
<th>Parasites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distillation or boiling</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>Chlorination</td>
<td>Fair-good</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
<td>Poor</td>
</tr>
<tr>
<td>Reverse osmosis</td>
<td>Good</td>
<td>Good</td>
<td>Not tested</td>
<td>Good</td>
<td>Not tested</td>
</tr>
<tr>
<td>Copper/silver ionization</td>
<td>Excellent†</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Not tested</td>
</tr>
<tr>
<td>Submicron filtration</td>
<td>NA</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Ozonation</td>
<td>Good</td>
<td>Not tested</td>
<td>Not tested</td>
<td>Excellent</td>
<td>Excellent</td>
</tr>
<tr>
<td>UV irradiation</td>
<td>Good</td>
<td>Poor</td>
<td>Not tested</td>
<td>Fair-poor</td>
<td>Excellent</td>
</tr>
<tr>
<td>Iodinated resin</td>
<td>Good</td>
<td>Poor</td>
<td>Not tested</td>
<td>Good</td>
<td>Poor</td>
</tr>
</tbody>
</table>

*Excellent indicates eliminates all microbes (highly effective); good, clinically significant reduction in microbial load; fair, some reduction in microbial load but questionable clinical relevance; and poor, little or no effect on microbial load (not clinically useful).
†Limited experience.
‡Likely to be effective.

RECOMMENDATIONS FOR PREVENTING NOSOCOMIAL WATERBORNE INFECTIONS

Government agencies have established guidelines for water safety in the community, particularly for immunocompromised persons.133-134 Given the greater vulnerability of these patients to infection when hospitalized (usually at the peak of their immunosuppression), hospitals caring for such patients should provide higher standards of drinking water quality than the community and should take immediate measures to prevent waterborne infections. These measures are likely to be successful, as demonstrated by the significant reduction in waterborne infections (such as legionellosis and cryptosporidiosis) when guidelines are applied.129,138

To this end, we offer the single new recommendation of minimizing patient exposure to tap water for all hospitalized immunocompromised patients and reinforce previously published recommendations, ie, to educate staff and patients, implement existing infection control measures, and perform targeted surveillance.

I. Minimize Patient Exposure to Tap Water: Inexpensive Yet Potentially Effective

This measure is the easiest and least expensive to implement. Its effectiveness has been demonstrated by studies in which provision of sterile water or avoidance of tap water markedly reduced the incidence of legionellosis129 and cryptosporidiosis138 and terminated several other outbreaks of nosocomial waterborne infections (Table 4).

We recommend implementation of the CDC guidelines136,137 regardless of the colonization of hospital water systems by Legionella species. We further recommend expanding these CDC guidelines to all immunocompromised patients. Our recommendations are based on the following: (1) culturing of hospital water for Legionella species is not routinely performed at most transplantation centers, as evidenced by the outbreaks of legionellosis on such units, which may go unrecognized for up to 10 years123-125; (2) opportunistic molds can inhabit hospital water systems and aerosolize after water activities, leading to patient exposure135,136; and (3) other hospitalized immunocompromised patient populations (cancer patients, solid organ transplant recipients, etc) are also at risk for legionellosis58 and other nosocomial waterborne infections.11-52

These patient populations should, thus, be offered the same level of protection given to recipients of hematopoietic stem cell transplants.

Sterile water can be produced by vigorous boiling for 3 minutes or can be purchased at a minimal cost ($0.49/gal average price). Of note, bottled water is not necessarily sterile unless so labeled. Other water disinfection technologies are available, but distillation seems to be the most appropriate approach to producing sterile water in small quantities (Table 5). However, extraordinary effort would be required to establish and maintain distillation systems sufficient to provide sterile drinking water to all hospitalized patients. Because of its low cost and worldwide availability, sterile drinking water (obtained by vigorous boiling or purchased as bottled water) should be provided to immunocompromised patients. Because showering is as-
sociated with nosocomial waterborne infections and results in aerosolization of pathogens, it would seem prudent to avoid showering and to rely instead on disposable sterile sponges for bathing. These sponges are inexpensive (<$1.50 per patient per day), require less nursing time in the bathing of patients compared with showering these patients or providing them with the usual self-prepared bed baths, and are well accepted by caregivers. Alternatively, patients may prepare their own sterile sponge bath with towels that have been steamed or microwaved and water that has been boiled. Special care must be taken to avoid serious burns in this setting. Appropriate disinfection of hospital equipment and avoidance of contact of such equipment with tap water is also recommended.

It could be argued that it was failure in infection control practices (such as failure to wash hands) that contributed to some of these waterborne outbreaks and that implementation of effective practices will suffice to prevent these infections. However, a significant rate of nosocomial infections (10%) persisted even after a significant improvement in compliance with hand hygiene (from 48% to 66%). In addition, and despite extensive education about the importance of infection control measures, adherence among health care workers remains low. Thus, a more redundant system needs to be put in place that relies on more than one method to prevent these infections. Provision of sterile water is an inexpensive measure that could provide such redundancy.

It could also be argued that institutions caring for high-risk patients have already undertaken such precautions. Such is not the case, however, as evidenced by the recent reports of outbreaks of legionellosis in transplantation units that went undetected for up to 10 years.

II. Educate Staff and Patients and Implement Existing Infection Control Measures

Hospital staff members and patients should receive education about the procedures that prevent infection from waterborne pathogens in hospital and outpatient settings (per US and United Kingdom public health agencies). Reinforcement of infection control measures that have ended outbreaks in the past is also needed. These measures include hand disinfection, use of other aseptic techniques, discontinuation of the use of contaminated equipment, restriction of equipment connection to water sources until immediately before use, effective instrument sterilization, and meticulous disinfection of the ward environment.

III. Perform Targeted Surveillance

Two approaches for the control of nosocomial legionellosis have been recommended: (1) intensive surveillance for infections and monitoring of water systems when infections occur and (2) routine surveillance cultures of water distribution systems in hospitals caring for high-risk patients.

Although we favor the latter approach in the case of legionellosis, we believe that intensive surveillance for infections other than by Legionella species is more appropriate until the extent of the relationship between infection and water colonization by these pathogens has been established. Such surveillance, however, should be intensive, comprehensive, and prolonged and should rely on appropriate tools to diagnose these infections and their relation to the water source.

IV. Other Measures

One potentially effective approach is to maintain hot water at 60°C or higher in an attempt to decrease the concentration of organisms in hospital water systems. However, we do not view this approach as particularly appealing because of the considerable costs, the short-term effectiveness of this measure, and the risk of accidental scalding injury of patients and staff.

New hospitals should construct water distribution systems that meet the American Institute of Architects specifications, and, per CDC and Association for Professionals in Infection Control and Epidemiology recommendations, all hospitals should conduct routine preventive maintenance of their water distribution system. Unlike residential water tanks, which are based on flow-through systems, large buildings such as hospitals are required to have recirculating hot water systems, which are associated with a significant increase in risk of colonization by and amplification of these pathogens. Water filtration systems are not consistently effective, are expensive, and are difficult to maintain. Thus, physical barriers (avoidance of exposure) remain the best forms of protection. This conclusion is supported by the lower cost, ease of implementation, and effectiveness of such measures compared with the high cost, complexity, and limited success of disinfection methods (waterborne organisms rapidly recolonize water structures). Important measures to decrease the concentration of organisms present in hospital water systems consist of repairing and disinfecting damaged and contaminated water systems (including tanks) and establishing a regular maintenance program.

The literature demonstrates a strong association between waterborne pathogens and nosocomial infections other than legionellosis. This association is not well appreciated and is still not fully understood. The most rigorous approach to better understanding the magnitude of the problem is the conduct of carefully planned prospective studies. These studies should prospectively assess the magnitude of the problem of nosocomial waterborne infections and the percentage of hospitals that have microbial contamination of their water supply. These studies should also attempt to correlate rates of nosocomial pneumonia with counts of waterborne gram-negative organisms such as P aeruginosa and with certain hospital practices such as superheating and flushing or other control methods for waterborne legionellosis.

This review does not demonstrate that instituting our new recommendation of avoiding patient exposure to tap water would result in a decreased incidence of all waterborne nosocomial infections. However, the effectiveness of this easy, inexpensive, and readily and widely available approach has been demonstrated by studies in which provision of ster-
ile water or avoidance of tap water markedly reduced the incidence of waterborne infections, including legionellosis and cryptosporidiosis, and terminated several other outbreaks of nosocomial waterborne infections (Table 4)."

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