Summary

A major increase in outbreaks of Legionnaires’ disease at U.S. hospitals in recent years has led to greater awareness of a problem lurking in the drinking water. With a mortality rate of 40% for hospital-acquired legionellosis – in part a result of lack of testing and appropriate treatment – the fact that approximately 70% of hospitals have *Legionella* bacteria in their water systems is a significant concern. Efforts to ameliorate this problem have led to the promulgate of a variety of remediation technologies, which in turn have caused significant confusion over which modalities to use, how to use them and in what potential combinations. One outbreak in particular, at the Pittsburgh VA Healthcare System, has led to a re-evaluation of technologies by the Centers for Disease Control and Prevention and the Veterans Health Administration. This paper attempts to sort through the clutter to present a balanced view of the challenges we face with this waterborne menace, and describe the relative advantages of the most successful long-term remediation technology – copper silver ionization.
Legionnaires’ disease, or legionellosis, is a serious, often lethal type of pneumonia that is caused by bacteria of the genus *Legionella*. Since 2001, Centers for Disease Control and Prevention surveillance reports have stated that *Legionella* is the single most commonly reported pathogen associated with drinking water outbreaks in the United States. Voluntarily reported cases of legionellosis tripled from 2000 to 2009 to 3,522 annually.\(^2\) The CDC estimates that the incidence is likely a multiple of that figure, and that as many as 18,000 people are hospitalized annually with the disease.

Dr. Paul Edelstein, director of the University of Pennsylvania Health System’s Clinical Microbiology Laboratory and a leading Legionnaires’ researcher, goes much further, estimating that the true number probably ranges between 56,000 and 113,000 cases annually, based on an incidence ratio of 180-360 cases per 1 million people reported from extensive testing in Germany.\(^3\) Even that figure may be conservative; Edelstein said studies have shown that common tests may not detect as many as 40% of Legionnaires’ cases.

The aging population may play a role in the increase in cases, as older people tend to have weakened immune systems, a key risk factor.

Twenty three percent of Legionnaire’s disease cases reported to the CDC are hospital-acquired, and those cases have twice the mortality rate of community-acquired infection – a staggering 40%. In a national survey of 192 hospitals, 29% reported having at least a single case of hospital-acquired Legionnaire’s disease and 16% reported greater than five cases.\(^4\) A range of studies has consistently found that approximately 70% of hospitals have *Legionella* in their water systems.

Although cooling towers were linked to the cases of hospital-acquired Legionnaires’ disease in the years after its discovery in 1976, drinking water has been the environmental source for almost all reported hospital outbreaks. During the 2005-2006 CDC surveillance period, 100% of the waterborne disease outbreaks associated with *Legionella* occurred as a result of colonization in plumbing and pipes and 80% occurred in a healthcare setting.

Once this source was discovered, prevention became possible through disinfection of drinking water systems.

*Legionella* is transmitted from water to air by aerosol-generating systems such as cooling towers, evaporative condensers, faucets and showerheads, humidifiers, respiratory therapy equipment, whirlpool baths and hospital water features such as fountains. Humans aspirate the bacteria.

*Legionella* bacteria are known to infect amoebae and protozoa, which live in the biofilm, the slime that lines water pipes. *Legionella* strains that multiply in protozoa have been shown to be more virulent, possibly due to increased bacterial numbers. The ability to proliferate within these hosts provides *Legionella* with protection from environmental conditions such as hot water and allows it to resist water treatment with chlorine, biocides and other disinfectants.

Many hospitals are unaware of the nature of this threat. A 1999 survey found that while 60% of respondent hospitals had on-site testing capabilities, just 21% had established routine *Legionella* testing of the water supply. Only a handful of health departments nationally have issued mandates for such testing. After experiencing outbreaks at its health facilities, the Veterans Health Administration requires its hospitals to either test water as part of a *Legionella* evaluation plan or screen patients for the bacteria. If 30% of water test sites are positive for the bacteria, VA hospitals must proceed with active surveillance of patients for *Legionella* infection, especially those at highest risk of infection (transplant or immunocompromised patients). There are no national standards for testing of either water or patients.
COPPER SILVER IONIZATION AND LIQUITECH®

Copper silver ionization has become the dominant modality for long-term remediation of Legionella, in use at hundreds of hospitals across the U.S. In this system, a flow cell chamber containing sacrificial copper/silver electrodes is attached to the water supply. A direct current is applied across these electrodes to stimulate the controlled release of ions. The ions form electrostatic bonds with negatively charged sites on microorganism cell walls. These bonds create stresses that lead to distorted cell wall permeability, reducing the normal intake of life-sustaining nutrients. This action, coupled with protein denaturation, leads to cell disintegration and death.

In LiquiTech’s system, a solid-state, microprocessor-based controller automatically maintains the rate at which ions are released. The accurate dose-rate control system maintains precise ion levels, providing residual protection and prevention of recontamination. A remote monitoring system allows engineers to track and control operation from anywhere. LiquiTech can also supervise the system via a web-based application, reducing significant hospital labor costs associated with maintenance.

The LiquiTech system has undergone years of intense scrutiny and analysis in the U.S. and around the world. In April 2013 it became the first copper silver ionization system to be recognized by the U.S. Environmental Protection Agency as having satisfied efficacy requirements to be able to make claims about the eradication of Legionella (U.S. EPA Reg. No. 68250-1). LiquiTech is in the process of seeking recognition by all state EPAs.

The full system (electronic control unit, flow cells and interconnecting wire) bears the appropriate ETL Listed Marks. All flow cell wetted components are NSF Standard 61-certified.

Copper silver ionization was selected by the Department of Defense as a requirement for all new healthcare projects in its Unified Facilities Criteria after a thorough evaluation of drinking water disinfection alternatives by the U.S. Army Corps of Engineers, the Naval Facilities Engineering Command and the Office of the Air Force Civil Engineer.

A Veterans Health Administration Information Letter on prevention of Legionella, dated May 3, 2013, states: “Engineering measures implemented in facility water distribution systems (e.g., copper silver ionization, chlorine dioxide) are critical for Legionella prevention.”

Overseas, the system is certified for the remediation of Legionella from drinking water by the Dutch Competent Authority CTGB (akin to the U.S. EPA/FDA). All components of the ionization chamber are KIWA-ETA-approved (Europe’s version of the NSF).

More than 1,400 LiquiTech systems have been installed in both hot and cold drinking water systems around the world over the past 20 years. The list of installations includes more than 350 of the largest and most prestigious healthcare facilities in the United States, most with some of the most immune-compromised patients. LiquiTech clients include:

- Memorial Sloan-Kettering Cancer Center, New York
- New York Presbyterian Hospital
- Northwestern Memorial Hospital, Chicago
- UCLA Medical Center, Los Angeles
- Virginia Mason Medical Center, Seattle
Copper Silver Ionization

Copper silver ionization is the only water disinfection method for which multiple field evaluations of efficacy have been published in the peer-reviewed literature. A study at the Pittsburgh VA Medical Center in 1994 found that compared to thermal heat and flush, ionization was more effective in controlling Legionella environmental positivity and occurrence of cases. The percentage of distal outlets – such as water taps and showerheads – with Legionella colonization was reduced from 75% to 0% in three months using the LiquiTech modality. “The advantages of copper silver ionization include relatively low-cost, straightforward installation, easy maintenance, non-toxic byproducts, and the presence of a disinfecting residual pneumonia from a hospital,” the study authors wrote.

National surveys of 16 hospitals by the same authors in 1995 and 2000 found that ionization was highly effective in preventing hospital-acquired Legionnaires’ disease across the U.S. The surveyed hospitals had had ionization in place for five to 11 years. At the time of the second study, the Pittsburgh VA Medical Center reported that zero cases of hospital-acquired Legionnaires’ disease occurred there from 1999 to 2002 – a trend that continued until an outbreak of the disease in 2011 and 2012. (We will return to this topic below.)

In a controlled study using a model plumbing system into which Legionella and other waterborne pathogens were introduced, copper silver ionization was found to be efficacious for control of biofilms and plankton-associated waterborne pathogens.

A major 2011 review of all of the existing modalities for remediation of Legionella found that “copper silver ionization appears to be the best available technology today for controlling Legionella colonization in hospital water systems.”

Still another study found that copper silver ionization is less expensive than hyperchlorination and provides residual protection throughout the water distribution system. This study did find that a disadvantage of the modality is that the system’s performance will suffer unless scale is removed regularly from the electrodes. A later version of that study identified the need to maintain a pH in the water of less than 9.2. In cases of high pH, the addition of a food-grade citric acid can reduce the pH and allow the system to operate effectively. (We will return to the topic of maintenance below.)

Advantages and Drawbacks of Other Modalities

From the early 1980s through 2008 the Special Pathogens Laboratory of the Pittsburgh VA Medical Center, in conjunction with the University of Pittsburgh Department of Environmental Engineering, analyzed and in some cases devised innovative approaches to water disinfection in hospitals. In fact, all of the methods in use today were first evaluated in controlled studies by the laboratory.

Thermal Disinfection

Thermal disinfection, otherwise known as super heat and flush, is a common practice for water distribution systems in hospitals, hotels and other institutional buildings. In this modality, the hot water temperature is elevated to above 158° F, and distal sites are flushed for as long as 30 minutes. In cases of outbreaks, thermal disinfection can be quickly implemented as emergency remediation. No special equipment is needed.

The disadvantages to this method are several, and include the potential for scalding, the cost of the energy needed to boost water temperatures and the expense for the many staff members required to monitor distal sites, tank water temperatures and flushing times. A Pennsylvania hospital estimated the cost of thermal disinfection at $80,000 per procedure. In addition, recolonization will occur within months because disinfection using this method is only temporary. Some patients, due to illness, disabilities, advanced age or side effects of medication, may be less sensitive to temperature and thus be at increased risk for tissue damage caused by extended exposure to hot water, even below the recommended threshold.

Hyperchlorination

Hyperchlorination entails the introduction of chlorinated salts to the water using a mechanical chlorinator. This raises chlorine levels throughout the system for one to two hours, long enough to kill bacteria. This method is efficacious in initial or emergency disinfection. Chlorine concentrations have to be monitored compulsively; if chlorine concentrations drop below disinfection levels, Legionella quickly re-enters the water distribution system, the Special Pathogens Laboratory found. This led to inconsistent efficacy.
This method has other drawbacks. It leads to corrosion of water pipes after five to six years of operation, and eventually parts of the system may be destroyed after pinhole leaks develop. Corrosion can be reduced by the use of a silicate coating on the water pipes. In addition, mechanical failure of the chlorinator, if not detected, could result in \textit{Legionella} recolonizing the system. More significantly, hyperchlorination may cause human health problems. Levels of carcinogenic trihalomethanes tend to increase in the hot water system when chlorine levels exceed 4mg/L.\textsuperscript{11}

\textbf{Chlorine Dioxide}

Chlorine dioxide is a synthetic gas. It is very different from elementary chlorine, both in its chemical structure and behavior. One of the most important qualities of chlorine dioxide is its high water solubility, especially in cold water, where it has proven to have some efficacy. It was first tried as a water biocide in Europe in the 1990s, where it proved ineffective. Later, Johns Hopkins University Hospital instituted chlorine dioxide and found that \textit{Legionella} incidence was reduced, but over a long period of time. It took 60 days to drop from 40\% to 20\% of water outlets testing positive, and another 15 months to reach the 4\% positivity level achieved at the end of the study period.\textsuperscript{12}

The Special Pathogens Laboratory evaluated of chlorine dioxide in the United States and also found that efficacy required almost one year of disinfection.\textsuperscript{13}

A significant drawback of chlorine dioxide is its volatility in certain applications, such as treating hot water environments. According to the American Water Works Association: “In the presence of (elevated water temperatures), or at high pH values, chlorine dioxide disproportionates to form both chlorite and chlorate, both of which are undesirable in drinking water.”\textsuperscript{14} Heat acts as a catalyst in a reaction that transforms the effective biocide into approximately 70\% chlorite. According to the EPA, some infants and young children who drink water containing excess amounts of chlorite can experience nervous system effects. Similar effects may occur in fetuses of pregnant women who drink water containing chlorite in excess of the maximum contaminant level. Some people may experience anemia.

\textbf{Monochloramine}

Monochloramine, a compound produced by adding chlorine to a solution containing ammonia, is considered effective against \textit{Legionella} in the biofilm of model plumbing systems. Two case-control studies have suggested that hospitals in municipalities that were supplied with domestic drinking water treated with monochloramine were less likely to report cases of hospital-acquired Legionnaires’ disease.

The efficacy of on-site monochloramine treatment in individual hospitals has not yet been studied over a prolonged period. A 2002 CDC study using a model plumbing system with biofilm containing \textit{Legionella} and other pathogens compared free chlorine and monochloramine as disinfectants. It found that monochloramine was significantly more effective than chlorine against \textit{Legionella} in a mixed culture bacterial biofilm.\textsuperscript{15}

\textbf{Ultraviolet Light}

Ultraviolet light is seen as a potentially attractive option for disinfection, since no chemicals are added to the drinking water. It is used to eradicate bacteria at the point where water enters the hospital from a municipal main. In a study at a new hospital facility, a UV disinfection system installed at the point of entry resulted in none of 930 cultures of drinking water over a 13-year period being positive for \textit{Legionella}, and no cases of hospital-acquired legionellosis being found.\textsuperscript{16}

However, a point-of-entry application does not allow distal eradication of \textit{Legionella} within the biofilm of a water distribution system. In fact, two hospitals have shown that UV was ineffective in eradicating \textit{Legionella} at distal sites. “Combination of UV with other treatment modalities was effective for individual hospital units,” the Special Pathogens Laboratory found.
Given the long-term success of the implementation of the copper silver ionization system at the Pittsburgh VA Medical Center, it came as a surprise that it was the site of a major outbreak of *Legionella* in 2011 and 2012 that killed five patients and sickened 27 others.

According to the CDC, which was called in to investigate the outbreak, 29 of 44 environmental samples collected by a field team in November 2012 showed growth of *Legionella*, including all 11 samples collected from sites immediately downstream of the copper silver ionization system. Nine samples were positive for the outbreak strain. In addition to the copper silver ionization system, the VA had used intermittent superheating during the outbreak. At the time of its investigation the CDC found the levels of disinfectant in the water were “appropriate for controlling *Legionella* according to the manufacturer’s recommendations and the hospital’s protocol.”

There are a number of issues with the CDC’s assertions. Despite repeated queries from LiquiTech and Freedom of Information requests from the media, the CDC has never released any data from the samples or described the sampling protocol. It cited mean levels of copper silver ions in the water, without citing the range of readings. In fact, in an investigative report by CBS News, in testimony in February 2013 before the U.S. House Committee on Veterans’ Affairs Subcommittee on Oversight and Investigations and in a VA inspector general’s report, a quite different story emerged.

Two years of lab data obtained by CBS News showed that the levels of copper silver ions required to keep *Legionella* bacteria at safe levels were often too low to control the bacteria, putting the hospital at risk of an outbreak.

Officials from LiquiTech and Enrich, Inc., another provider of copper silver ionization, testified before Congress that when they were called in by Pittsburgh VA officials to check the prevention system, they found the equipment was not being properly maintained and was being monitored by untrained staff members. There was significant scale buildup on the flow cells, and the systems were run in continuous mode, so that ions were not being released in proportion to the demand on the system. Furthermore, three LiquiTech employees found VA employees falsifying records on copper silver ion levels, an assertion the VA has never denied.

During the congressional hearing, Congressman David P. Roe of Tennessee questioned Dr. Lauri Hicks, a medical epidemiologist with the CDC who led the investigation, as to why if the copper silver ionization system was used for a decade without a single case of *Legionella*, suddenly the testing found *Legionella* despite the ions being within acceptable range. “I think that is a question that we would like to look into more,” she said. “We have not had many opportunities to really evaluate the system. This was actually our first field investigation into an outbreak where there was a copper silver system.” She said in response to another question that the CDC has “received anecdotal reports from other facilities that have also had trouble” with copper silver ionization systems.

LiquiTech is installed in 15 VA facilities across the nation. In no other cases has there been a case of *Legionella* or any reported problems, the company has stated.

Dr. Hicks also erroneously stated that only two methods for disinfection of water systems approved by the EPA are chlorine and chlorine dioxide. As noted above, copper silver ionization is registered to control *Legionella*.

The committee also heard from Dr. Victor Yu and Dr. Janet Stout, two nationally renowned experts on *Legionella*, who founded and ran the Special Pathogens Laboratory at the Pittsburgh VA. It became the center of *Legionella* research across the globe, and its abrupt closure in 2006 under questionable circumstances was followed by a congressional hearing in 2008 that led to the exoneration of both Stout and Yu.

Both of the former lab directors cited the failure to maintain the LiquiTech system as a major cause of the *Legionella* outbreak, a finding echoed at the conclusion of the hearing by U.S. Rep. Mike Coffman, the chairman of the House Oversight Subcommittee.

The VA’s own Office of the Inspector General, in a report requested by Congress and the VA Secretary, also concluded that the Pittsburgh VA system failed to maintain the system, resulting in inadequate copper silver ion levels for *Legionella* control to persist. “There was a lack of documentation of system monitoring for substantial periods of time and inconsistent communication and coordination between the Infection Prevention Team and Facility Management Service staff,” the report found. “We also found that VAPHS did not conduct routine flushing of hot water faucets and showers, especially in areas that are infrequently used, as recommended by the copper silver ionization system manufacturer.”
The importance of the proper maintenance of a copper silver ionization system was further underscored by submitted testimony from Edward Dudek, Assistant Vice-President, Facilities, Engineering & Maintenance at Pittsburgh’s UPMC Presbyterian Hospital; and Carlene A. Muto, MD, MS, Medical Director of Infection Prevention and Hospital Epidemiology at UPMC’s Presbyterian Hospital Center for Quality, Safety and Innovation. LiquiTech's controller and flow cells are installed throughout UPMC Presbyterian Hospital, a large academic facility with five separate and isolated domestic hot water systems.

UPMC staff test the copper levels two times per week. Monthly they collect water samples from numerous areas throughout the building and from each individual hot water system loop. The copper and silver levels in these water samples are tested monthly through an outside laboratory using atomic absorption. All system adjustments are made based on the independent atomic absorption lab test results. In addition to the cell in service on each system, there is a spare cell always on site. The cells in service are checked bi-weekly for operation and are cleaned as required.

“In summary ... while copper silver ionization is one of the most effective and cost-effective methods available, the success of any disinfection modality is dependent not only on the equipment, but also on the overall hot water system management, the consistency of Legionella surveillance, water monitoring, duration of the disinfection measure and cooperation among the Infection Control personnel, Engineering Staff and Administration,” Dudek and Muto wrote.

In the wake of the findings, the CDC began a reconsideration of its own standards for Legionella testing and stated that an evaluation all of the remediation modalities based on comparative effectiveness was in order. Meanwhile, a VA Work Group of subject matter experts (engineering, infectious diseases, infection prevention and control, public health, occupational safety and health, laboratory, construction and facilities management) was convened to review and revise existing VA Legionella prevention policies.

ONE HEALTH SYSTEM’S CASE HISTORY

St. Elizabeth Healthcare, a multifacility healthcare provider in northern Kentucky and greater Cincinnati, has long taken a proactive stance on infection control. Its Legionella disease prevention plan, launched in 1997 when the issue became a local concern, enabled it to mitigate Legionella and other waterborne pathogens within its facilities.

Of four water disinfection systems investigated by hospital staff, St. Elizabeth chose copper silver ionization. “In addition to being environmentally safe, it was also long-term and cost-effective as it continuously treats biofilm in the domestic water without the need to shut down the system,” wrote Matthew Greis, systems director for plant engineering, operations and maintenance at St. Elizabeth, in Modern Healthcare magazine. “The chlorination option required that the system be shut down for hours to allow the chlorine to work. Similarly, the thermal eradication option required superheating the water, which meant shutting the system to let it cool or risk burning patients. Ultraviolet irradiation was not a systemic solution and was incapable of eradicating bacteria throughout the entire facility.”

St. Elizabeth also implemented random sampling and testing as well as preventive maintenance, which included checking any areas where water might remain stagnant. “The system is easy to maintain, and we know it is working because sampling continues to produce negative results,” Greis wrote.
CONCLUSION

When properly maintained and as part of a larger program of regular testing and vigilance, the LiquiTech copper silver ionization system is the state-of-the-art modality for preventing and remediating *Legionella*, a set of bacteria that leads to the highest mortality rate of any healthcare-acquired infection.

In the wake of an outbreak, there are always pointed fingers and reevaluations, but a 20-year track record of success in eliminating these deadly bacteria weighs more heavily than any single episode. In fact, it can be stated without equivocation that there has never been a single case of Legionnaires’ disease at a hospital where LiquiTech has been installed and properly maintained over time. That is a claim that no provider of any other remediation modality can make with any credibility.

Working together with a growing list of healthcare clients, as well as those in numerous other industries, LiquiTech is striving to eliminate these highly preventable bacteria from water systems around the nation and the world.

REFERENCES

1 “Role of Environmental Surveillance in Determining Risk for Hospital-acquired Legionellosis: A National Surveillance Study with Clinical Correlations,” *Infection Control and Hospital Epidemiology*, July 2007


