

## Controlled Evaluation of Copper-Silver Ionization in Eradicating *Legionella pneumophila* from a Hospital Water Distribution System

Zeming Liu, Janet E. Stout, Lou Tedesco, Marcie Boldin,  
Charles Hwang, Warren F. Diven, and Victor L. Yu

Departments of Medicine and Engineering, University of Pittsburgh and  
VA Medical Center, Pittsburgh, Pennsylvania

A controlled evaluation was made of the efficacy of copper-silver ionization in eradicating *Legionella pneumophila* from a hospital water supply. Copper-silver ionization units were installed on the hot water recirculation line of one building with water fixtures positive for *Legionella* species. Another building with the same water supply served as a control. *Legionella* species persisted within the system when copper and silver concentrations were <0.3 and <0.03 ppm, respectively. When copper and silver concentrations were >0.4 and >0.04 ppm, respectively, there was a significant decrease in *Legionella* species colonization, but the percentage of water fixtures positive for organisms was unchanged in the control building. When the ionization unit was inactivated, water fixtures continued to be free of *Legionella* species for 2 additional months. Copper-silver ionization can eradicate *L. pneumophila* in a water distribution system. The advantages of copper-silver ionization include relatively low cost, straightforward installation, easy maintenance, nontoxic by-products, and the presence of a disinfecting residual.

*Legionella pneumophila* in the hospital water distribution system has been epidemiologically linked to hospital-acquired legionnaires' disease [1-5]. Control of nosocomial outbreaks has been accomplished by disinfecting the hospital water distribution system. Superheat and flush and hyperchlorination have been commonly applied despite disadvantages of both of these methodologies [6].

Copper-silver ionization by electrolysis is theoretically an attractive alternative for disinfecting potable water systems. The electrode emissions created by the ionization process are

anionic, surface-active, and microbiocidal. The disinfecting action is attributed to the positively charged copper and silver ions, which form electrostatic bonds with negatively charged sites on the organism's cell wall. These electrostatic bonds create stresses leading to distorted cell wall permeability. This action, coupled with protein denaturation, leads to cell lysis and death. Ionized copper and silver have been shown to be efficacious in vitro in killing *L. pneumophila* species [7]. However, the actual efficacy of copper-silver ionization disinfection of *L. pneumophila* species in the actual potable water systems is uncertain despite installation of these systems in several hospitals [8, 9].

We examined the efficacy of copper-silver ionization as a disinfection method in a hospital building persistently colonized with *L. pneumophila*. The superheat and flush method, shock hyperchlorination, and installation of an instantaneous steam heater had been ineffective in the building. Our

---

Received 16 July 1993; revised 29 November 1993.

Reprints or correspondence: Dr. Victor L. Yu, Infectious Disease Section, VA Medical Center, University Drive C, Pittsburgh, PA 15240.

The Journal of Infectious Diseases 1994;169:919-22  
© 1994 by The University of Chicago. All rights reserved.  
0022-1899/94/6904-0037\$01.00

objectives were to determine the efficacy of the copper-silver ionization system alone for elimination of *Legionella* colonization of a hospital water system and to determine the extent of monitoring and maintenance necessary to keep the units operational.

## Materials and Methods

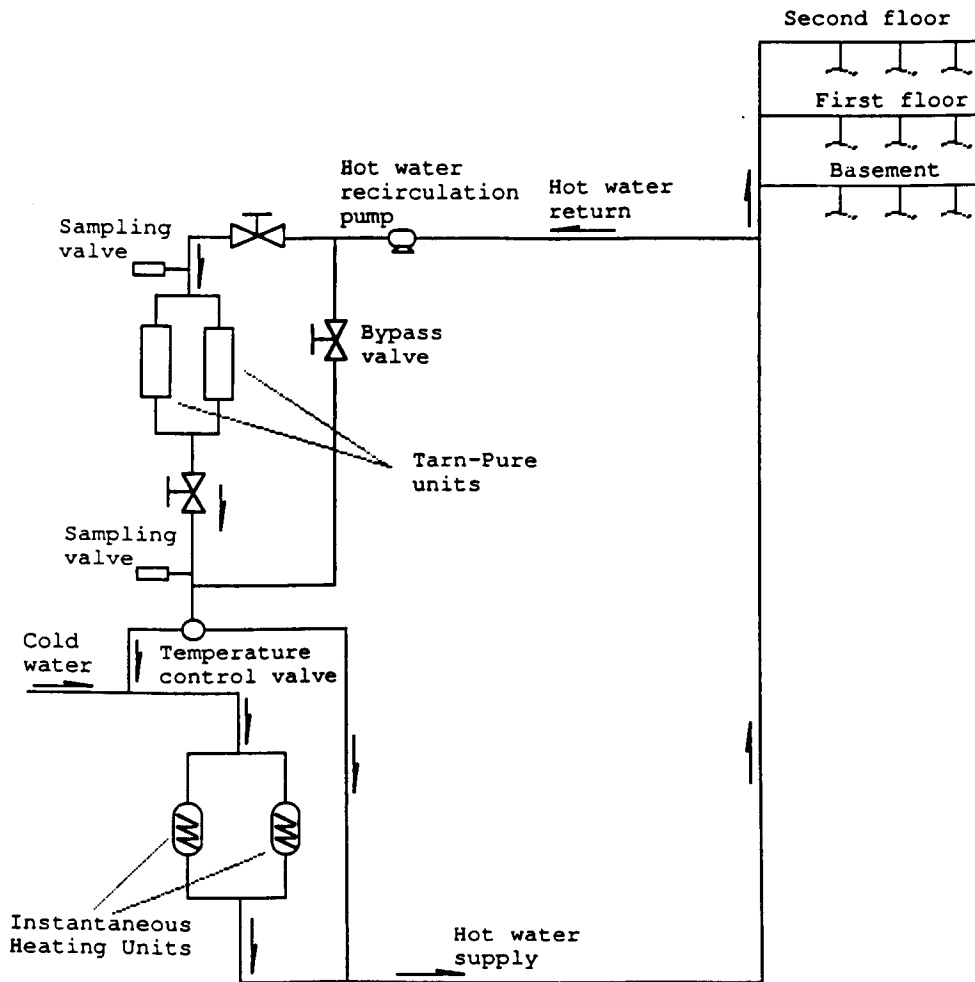
**Hospital.** The study was undertaken in a 541-bed VA medical center that provides services to veterans with psychiatric disorders. Of patients at the test site, 96% were ambulatory.

**Copper-silver ionization system.** The copper-silver ionization system (LiquiTech, Burr Ridge, IL) electronically introduces copper and silver ions into water from electrodes made from a specially formulated copper-silver alloy. The rate at which the ions are liberated from the electrode surface is automatically maintained by solid-state, microprocessor-controlled circuitry. Six copper-silver electrodes (three pairs) are housed in a flow-through chamber. The output current is adjustable at the control unit and was set at 3 A, 40 V. The electrodes were cleaned once a month and whenever the amperage dropped to <2 A or the copper concentration level was <0.1 ppm.

Copper analysis was done at the time of sample collection using a test kit (model STC-CTP; LaMotte Chemical, Chestertown, MD). Both copper and silver ion concentrations were subsequently determined by atomic absorption spectroscopy [10, 11].

**Water distribution systems.** Two buildings were chosen as the test and control buildings. Both had the same water supply with two instantaneous steam heating units. There were no hot water storage tanks. Two copper-silver ionization flow cells (model XTPF36-4/3) were installed in parallel on the hot water recirculation line of the test building (figure 1). This model can accommodate a maximum flow rate of 378.5 L/min. Cultures before installation of copper-silver ionization units showed that 17 (65%) of 26 distal water sites at the test building and 11 (52%) of 21 water fixtures at the control building were colonized with *L. pneumophila*. On rare occasions, *Legionella bozemanii* was also isolated.

**Environmental monitoring for legionellae.** Swabs of the surfaces of showerheads and inner surfaces of water spigots were cultured. Samples were obtained before start-up, 1 week after the system was installed, and monthly thereafter. Swabs were acid treated, and then 0.1 mL of a sample was plated onto buffered charcoal yeast extract agar and selective medium contain-



**Figure 1.** Schematic of copper-silver ionization units installed in parallel on hot water recirculation line for test building.

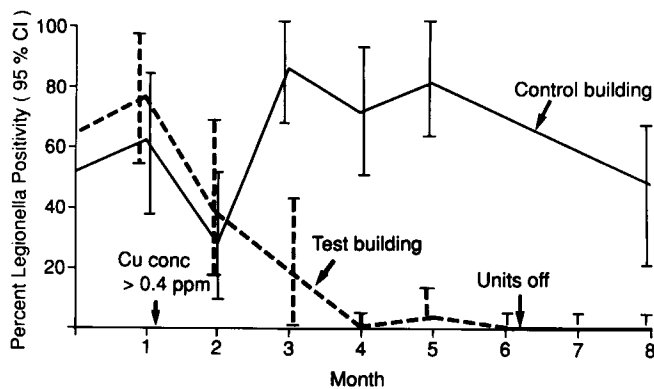
ing dyes, glycine, vancomycin, and polymyxin B as part of a standardized culture protocol [12]. Water samples were collected from the recirculation line before and after the water passed through the ionization units.

**Assessment of copper-silver ionization efficacy.** The copper-silver ionization system (maximum power output: 0.5 A, 32 V) was activated without prior disinfection of the piping and distal sites. One pair of electrodes was connected. At 4 and 6 weeks, additional pairs of electrodes were installed because of suboptimal copper and silver concentrations. Finally, a higher power output controller was installed at 8 weeks (maximum: 5.0 A, 50 V).

**Statistical analysis.** The culture results from the test and control buildings were compared by percentage and mean percentages of positive test sites in the test and control buildings ( $\chi^2$  test and *t* test of unequal variance, respectively).

## Results

When the system was activated, copper and silver concentrations were 0.05 and 0.001 ppm, respectively. Four weeks later, the concentrations were 0.1 and 0.001 ppm. After 8 weeks, the copper and silver concentrations still did not exceed 0.2 and 0.001 ppm, respectively. During this period, no change in the rate of *L. pneumophila* positivity in the test building was documented (figure 2). After a more powerful control unit was installed, the copper and silver concentrations reached 0.4 and 0.04 ppm, respectively, within 1 week. The *L. pneumophila* positivity rate then began a sustained and statistically significant decrease within 4 months after activation of the unit (figure 2). Before activation of the copper-silver unit, there were no significant differences in *L. pneumophila* positivity between the test building (50%) and the control building (57%); however, by 6 months after activation of the unit, the mean percentage of positive sites was significantly less in the test building (0.8%) than in the control building (67%;  $P = .02$ , *t* test of unequal variance).



**Figure 2.** Effect of copper-silver ionization on *Legionella* positivity. When copper-silver concentration reached 0.4 ppm, *Legionella* positivity showed significant gradual decrease ( $P < .05$ , *t* test of unequal variance and  $\chi^2$  test). Cu conc = copper ion concentration.

After the initial drop in distal site positivity, we hypothesized that the sites that remained positive were used infrequently. Therefore we opened the hot water spigots at these sites every other day for 2 weeks to allow these sites to be exposed to the copper and silver ions; subsequently, *L. pneumophila* disappeared from these sites. The control building remained at about the same level of *L. pneumophila* positivity as before the test start-up (28%–86%).

After 6 months, the units were turned off to assess the duration of time required for recolonization. The test building remained negative for *L. pneumophila* for 2 months, and only 1 (4%) of 26 sites was positive by 4 months. The control building remained *L. pneumophila*-positive (48%–62%).

Variation in copper-silver concentrations were documented at different times of the day (data not shown): Samples taken during periods of low-water usage (12 midnight to 5 A.M.) showed higher copper and silver concentrations than those taken during periods of high water use (7 A.M. to 12 noon).

## Discussion

The copper-silver ionization system of disinfection is a relatively new technology that has been used for disinfection of swimming pools [13]. We installed the ionization units in a hospital that had been persistently colonized with *L. pneumophila*. Prior efforts to prevent colonization by *L. pneumophila* (instantaneous steam heating system, superheat and flush, and shock chlorination) had failed.

Two months after the copper-silver ionization system was activated, the copper and silver concentrations remained  $<0.3$  and  $<0.03$  ppm, respectively; there was no change in the *L. pneumophila* positivity of distal sites. This copper concentration was not effective in killing *L. pneumophila* either because the ions could not penetrate the biofilm containing the organism or it could not kill the organism directly. When the copper and silver concentrations were increased to 0.4 and 0.04 ppm, respectively, a gradual and statistically significant decrease in *L. pneumophila* positivity at distal sites was documented monthly thereafter ( $P = .02$ ; figure 2). Of interest, Landeen et al. [7] also found that the critical copper and silver concentrations for killing *L. pneumophila* were 0.4 and 0.04 ppm, respectively. The fact that this disinfection succeeded without immediate prior disinfection (e.g., by superheat and flush or shock hyperchlorination) documents the disinfecting properties of the copper and silver ions.

An *L. pneumophila* disinfection program has been in place 6 years at our institution, but it was not until the copper-silver ionization system was used that distal water sites remained *Legionella*-free for  $>2$  months. Even more dramatic was the fact that after the unit was deliberately turned off, the distal sites remained free of *L. pneumophila* for  $>3$  months and  $<15\%$  of sites sampled were positive for an additional month.

The following points should be considered by any institution considering use of a copper-silver ionization system for *L. pneumophila* disinfection. The concentration of ions in the water system was dependent on water use; the more water used, the lower the concentrations of copper and silver were. During periods of high water use, copper and silver ions would drain from the recirculation line and be replaced by untreated water. During this period, the concentrations of copper and silver were low (<0.2 and <0.02 ppm, respectively). However, during periods of low water use and maximal recirculation through the ionization unit, copper and silver ions attained concentrations of 0.4–1.4 and 0.04–0.14 ppm, respectively.

Our experiment was done in a building with relatively low water volume (total volume in the hot water recirculation line, <189.3 L) and no hot water storage tank. It may be more difficult to maintain the concentrations of copper and silver at >0.4 and >0.04 ppm, respectively, in a larger building with greater water volume. Alternatively, a storage tank would provide larger volumes of treated water for delivery to hospital floors. The copper-silver ionization system was successful in eliminating *L. pneumophila* from water fixtures by treating only the hot water recirculation line. This approach proved effective in eradicating *L. pneumophila* from water fixtures even though cold water was not treated. The number of copper and silver ions ingested by patients or personnel were minimized since most water consumed comes from the cold water supply. Copper and silver levels should be monitored to conform with US Environmental Protection Agency (EPA) standards for drinking water, that is, 1.3 ppm copper and 0.1 ppm silver. Only 1 water sample (<1% of all samples collected) exceeded EPA standards.

Finally, optimal efficacy requires that the electrodes be cleaned regularly; frequency depends on water quality. Accumulated deposits of scale and sediment diminish the generation of copper and silver ions by the electrodes.

In summary, a copper-silver ionization system installed on the hot water recirculation line was effective in eradicating *L. pneumophila* from the water distribution system of a hospital building. The advantages of this system included easy installation and maintenance; nontoxic by-products well below EPA standards; stable and easily measured disinfectant residual that was unaffected by higher temperatures, unlike chlorine and ozone, which are degraded by high temperatures [14]; and a margin of safety, since recolonization by *L. pneumophila* required >2 months.

### Acknowledgments

We thank Jack Rugh, William Laitinen, Art Patterson, and Mary DeRiso for engineering and technical support, Daniel van Kammen and Reedes Hurt for administrative support, and Shirley Brinker for secretarial support.

### References

1. Fisher-Hoch SP, Tobin JO'H, Nelson AM, et al. Investigation and control of an outbreak of legionnaires' disease in a district general hospital. *Lancet* 1981;1:932–6.
2. Best M, Yu VL, Stout J, Goetz A, Muder RR, Taylor F. Legionellaceae in the hospital water supply—epidemiological link with disease and evaluation of a method of control of nosocomial legionnaires' disease and Pittsburgh pneumonia. *Lancet* 1983;2:307–10.
3. Korvick J, Yu VL, Fang GD. The role of *Legionella* sp. in nosocomial pneumonia. *Semin Respir Infect* 1987;2:34–47.
4. Snyder MD, Siwicki M, Wireman J, et al. Reduction in *Legionella pneumophila* through heat flushing by continuous supplemental chlorination of hospital water. *J Infect Dis* 1990;162:127–32.
5. Struelens MJ, Maes N, Rost F, et al. Genotypic and phenotypic methods for the investigation of a nosocomial *Legionella pneumophila* outbreak and efficacy of control measures. *J Infect Dis* 1992;166:22–30.
6. Muraca PW, Yu VL, Goetz A. Disinfection of water distribution systems for *Legionella*: a review of application procedures and methodologies. *Infect Control Hosp Epidemiol* 1990;11:79–88.
7. Landeen LK, Yahya MT, Gerba CP. Efficacy of chlorine and silver ions and reduced levels of free chlorine in inactivation of *Legionella pneumophila*. *Appl Environ Microbiol* 1989;55:3045–50.
8. Thomson RB, File TM, Plouffe J, Stephens C, Ricks R. Use of Tarn-Pure to eradicate *Legionella pneumophila* from a hospital hot water system [L18 abstract]. In: Proceedings of the annual meeting of the American Society for Microbiology (Anaheim, CA). Washington, DC: ASM, 1990.
9. Baker RL, Stevens J, Fish L, Crigger D. Nosocomial legionnaires' disease controlled by UV light and low level silver/copper ions (72 abstract). In: Proceedings of the Third International Conference on Nosocomial Infections (Atlanta, GA), 1990.
10. American Public Health Association. Standard methods for the examination of water and wastewater. 16th ed. Washington, DC: APHA, 1985.
11. US Environmental Protection Agency. Methods for chemical analysis of water and wastes. Cincinnati: US EPA, 1983; EPA 600/4-79-020.
12. Vickers RM, Stout JE, Yu VL, Rihs JD. Culture methodology for the isolation of *Legionella pneumophila* and other Legionellaceae from clinical and environmental specimens. *Semin Respir Infect* 1987;2:274–9.
13. Yayha M, Landeen LK, Kutz SM, Gerba CP. Swimming pool disinfection: an evaluation of the efficacy of copper-silver ions. *J Environ Health* 1989;51:282–5.
14. Muraca P, Stout JE, Yu VL. Comparative assessment of chlorine, ozone, and UV light for killing *Legionella pneumophila* within a model plumbing system. *Appl Environ Microbiol* 1987;53:447–53.