ARTICLES

Efficacy of thermal treatment and copper-silver ionization for controlling *Legionella pneumophila* in high-volume hot water plumbing systems in hospitals

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Background: Thermal treatment and copper-silver ionization are often used for controlling *Legionella pneumophila* in high-volume hospital plumbing systems, although the comparative efficacies of these measures in high-volume systems are unknown.
Methods: Thermal treatment of a hot water circuit was accomplished by flushing hot water (>60° C) through distal fixtures for 10 minutes. Copper-silver ionization was conducted in three circuits by installing units into return lines immediately upstream from hot water tanks. Recovery rates of *L. pneumophila* were monitored by culturing swab samples from faucets. Concentrations of copper and silver in water samples were determined by atomic absorption spectrophotometry.
Results: Four heat-flush treatments failed to provide long-term control of *L. pneumophila*. In contrast, ionization treatment reduced the rate of recovery of *L. pneumophila* from 108 faucets from 72% to 2% within 1 month and maintained effective control for at least 22 months. Only three samples (1.9%) of hot water from faucets exceeded Environmental Protection Agency standards for silver, and none exceeded the standards for copper. Of 24 samples obtained from hot water tanks, 42% and 50% exceeded the silver and copper standards, respectively.
Conclusions: Copper-silver ionization effectively controls *L. pneumophila* in high-volume plumbing systems and is superior to thermal treatment; however, high concentrations of copper and silver can accumulate at the bottom of hot water tanks. (AJIC Am J Infect Control 1997;25:452-57)

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Legionella pneumophila is frequently found in hot water plumbing systems in hospitals.[1-3] Hospitalized patients can acquire legionellosis by inhaling aerosols that contain *L. pneumophila;* these aerosols can be formed when water from the hot water circuit travels through showerheads and faucets.[4-6] Although thermal treatment and hyperchlorination are often recommended for controlling outbreaks of legionellosis in hospitals, these measures have serious drawbacks.[7] Thermal treatment is expensive in terms of labor costs, and because chlorine is corrosive to metal pipes, hyperchlorination may result in increased expenses for maintenance of the hot water plumbing system.

Recently copper-silver ionization has been introduced into hospitals for control of *L. pneumophila* in hot water plumbing systems. The ionization system generates copper and silver ions that bind to bacterial enzymes and DNA, leading to cell death.[8,9] The system also provides stable residual activity against *L. pneumophila* and thus may be superior to hyperchlorination, ultraviolet irradiation, and thermal treatment control measures.[7] Studies of hot water systems in hospitals suggest that copper-silver ionization eliminates *L. pneumophila* contamination in systems with relatively low water volume (i.e., <200L) and no hot water storage tanks.[2,10]

This study was conducted in a hospital shortly after the occurrence of two nosocomial cases of legionnaires' disease in children. Molecular fingerprinting studies identified the hot water plumbing system in Wing A of the hospital as the probable source of *L. pneumophila* for both cases.[11] Thermal treatment and copper-silver ionization were evaluated for control of *L. pneumophila* in the high-volume hot water plumbing systems in this hospital.

METHODS

Hospital plumbing system. The hospital is comprised of two adjacent structures (Wings A and B) that are connected at every floor. Wing A contains two independent hot water circuits, each of which is connected to separate 3790 L hot water tanks. The total water volume in each circuit is approximately 9500 L. Wing B contains a single hot water circuit connected to two 9500 L hot water tanks. The total water volume in this circuit is approximately 30,000 L. The hot water tanks in both wings are heated with centrally located steam bundles.

Thermal treatment. A hot water circuit was treated thermally by elevating the temperature of the water in the hot water tanks to exceed 70° C and flushing every distal fixture for at least 10 minutes with water exceeding 60° C, as described by Muraca et al.[7]

Copper-silver ionization system. The copper-silver ionization system (LiquiTech, Inc., Willowbrook, Ill.) consisted of a flow-through cell containing two sets of four copper-silver electrodes (Fig. 1). A single cell was installed into each hot water circuit approximately 2 to 10 linear feet upstream from where the return lines were connected to the hot water tanks (Fig. 2). The ionization system was operated and maintained according to the manufacturer's instructions. Samples of hot water were obtained for copper and silver analysis from a set of selected faucets during the follow-up period, but inadvertently baseline samples were not taken. These samples were obtained after allowing the hot water to run through the faucet for 1 minute. Selected samples from hot water tanks were also analyzed for copper and silver. Copper and silver levels were measured by atomic absorption spectrophotometry.

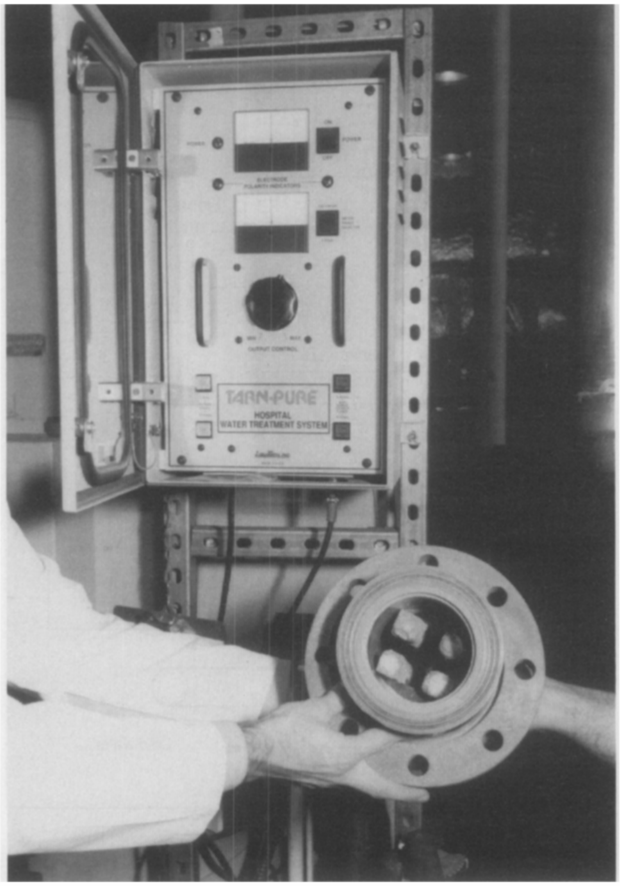

Fig. 1. Flow-through cell shows the upper set of four copper-silver electrodes (end view) and the controller unit (background). The condition of the electrodes after 13 months of use and a recent descaling treatment is shown.

Isolation and identification of *L. pneumophila*. *L. pneumophila* positivity in the hot circulating water systems was determined by sampling distal faucets with sterile swabs and by collecting water from the bottom drain valves of hot water tanks.[1] The same set of faucets was used for collecting the baseline and follow-up samples. Samples were inoculated onto differential glycine-

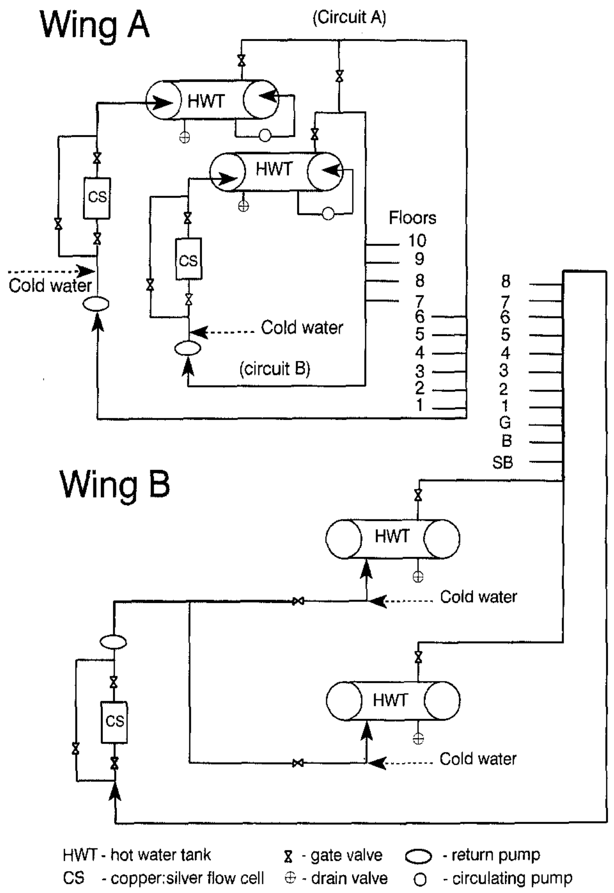

Fig. 2. Location of copper-silver ionization units in the hot water return lines of a hospital plumbing system. The gate valve in the cross connection between circuits A and B in Wing A is routinely kept in the closed position. To maintain a supply of hot water for all floors when one of the hot water tanks requires service, the valve is opened.

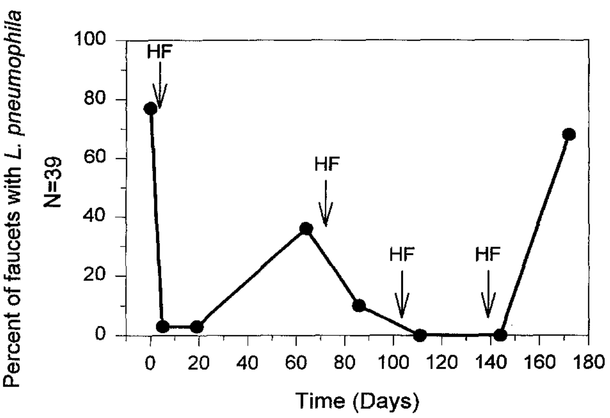

Fig. 3. Effect of heat-flush treatments on *L. pneumophila* colonization of distal sites of a hot water circuit in Wing A. Times are in relation to the baseline sampling done on day 0. *HF,* Heat-flush treatment.

vancomycin-polymyxin B agar (Remel, Lenexa, Kan.).[1,12] The cultures were incubated for 7 days at 37° C. Samples yielding more than 50 colony-forming units (CFU) of nonlegionellae bacteria per plate were processed by low pH treatment[13] and recultured onto the selective medium. The identification of *L. pneumophila* was confirmed with direct fluorescent antibody testing[14]; all isolates belonged to serogroup 1.

Statistical analysis. Differences in concentrations of copper and silver ions were analyzed by the Wilcoxon rank sum test, and *p* values were determined with the Epistat software program.[15]

RESULTS

Effect of thermal treatment. Immediately after the recognition of the second case of legionnaires' disease, thermal treatment was instituted in the hot water circuit in Wing A, which was identified as the probable source of legionellosis,[11] because this procedure could be implemented quickly and without acquisition of expensive equipment.[7] The rate of recovery of *L. pneumophila* from 39 faucets decreased dramatically in response to the initial heat-flush treatment but then increased to 36% within 61 days of the treatment (Fig. 3). Accordingly a series of three additional heat-flush treatments were instituted, and in response to these treatments, the rate of recovery of *L. pneumophila* decreased to 0% (Fig. 3). Within 29 days of the last treatment, the positivity rate returned to near the baseline level.

Effect of copper-silver ionization. Failure to maintain long-term control of *L. pneumophila* with thermal treatment led to the installation of copper-silver ionization units into each of the three hot water circuits. Similar recovery rates for *L. pneumophila* were obtained from faucet samples in each of the two Wing A circuits, and these results were therefore combined. The recovery rates from faucets in each wing decreased dramatically within 1 month of installation of the units and remained below 4% both throughout the first 12 months of follow-up and at the 22-month follow-up period (Fig. 4). This response occurred even though the mean concentrations of copper fluctuated widely; in contrast, mean concentrations of silver were relatively stable (Fig. 4). None of the hot water samples from the faucets contained copper at a concentration exceeding the United States Environmental Protection

Agency (EPA) treatment action level of 1300 parts per billion (PPB), but three samples (1.9% of the total) contained 110 to 140 PPB of silver. This silver level exceeds the EPA secondary maximum contaminate level of 100 PPB.[16]

Concentrations of *L. pneumophila* in the hot water tanks in Wings A and B immediately before installation of the units were 530 to 700 CFU/ml and 21 to 24 CFU/ml, respectively. Within 1 month of operation they decreased to undetectable levels (<1 CFU/ml) and remained undetectable throughout 11 months of follow-up. At the 12-month follow-up period, samples from two of the four tanks (one in each wing) yielded relatively low concentrations of *L. pneumophila* (i.e., 1 to 2 CFU/ml). Similarly, at the 22-month follow-up period, one of the four hot water tanks yielded a low concentration of *L. pneumophila* (i.e., 1 CFU/ml).

Hot water tanks are important reservoirs of *L. pneumophila* in hot circulating water systems.[1] *L. pneumophila* multiplies in the sediment that accumulates in the bottom of the tanks and may disseminate from this site and colonize distal plumbing fixtures.[17-20] Accordingly, the success in controlling *L. pneumophila* in the hot water circuits and tanks within the first 5 months of operating the ionization system suggested that copper and silver may have accumulated at the bottom of the hot water tanks and inhibited *L. pneumophila* multiplication. Concentrations of copper and silver were therefore measured in samples obtained from the tanks at follow-up periods of 6, 7, 8, 9, 12, and 22 months. Copper concentrations exceeded the EPA standard in 9 of 12 samples from Wing A (median, 9655 PPB; range, 50 to 128,000 PPB) versus 1 of 12 samples from Wing B (median, 298 PPB; range, 64 to 6524 PPB) (p = 0.012). Similarly, silver concentrations exceeded the EPA standard in 8 of 12 samples from Wing A (median, 1728 PPB; range, 32 to 314,200 PPB) versus 4 of 12 samples from Wing B (median, 40.5 PPB; range, <4 to 1269 PPB) (p = 0.017). The higher concentrations of copper and silver in samples obtained from the bottom drain valves of tanks in Wing A compared with those in Wing B were unexpected because the tanks in Wing A have circulating pumps designed to minimize accumulation of sediment at the bottom of the tanks, whereas the tanks in Wing B do not have circulating pumps. The differences may be related to (1) the higher volume of water in the tanks in Wing B compared with the tanks in Wing A; (2) differences in composition of the tanks, because the tanks in Wing A were constructed of steel and lined with concrete, whereas those in Wing B were constructed of copper; or (3) some other unknown factor.

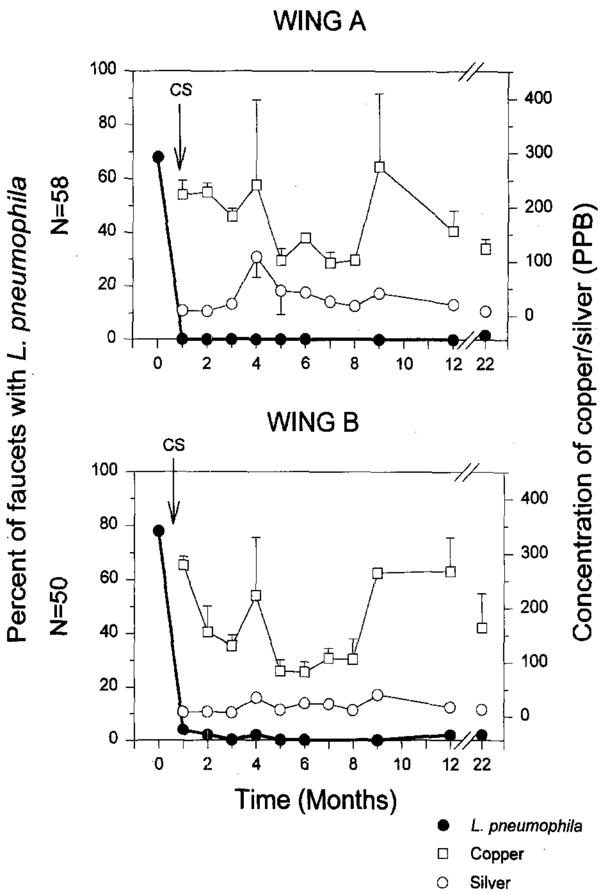

Fig. 4. Effect of copper-silver ionization system on *L. pneumophila* colonization of distal sites of hot water circuits. Times are in relation to the baseline sampling done on day 0. *CS arrow* signifies that copper-silver ionization was instituted shortly after collection of the baseline samples. Datum points corresponding to copper and silver concentrations represent mean values from 4 to 10 separate samples of hot water collected from different faucets. *Bars* represent standard errors. Datum points without bars indicate that the bars are smaller than the symbols.

DISCUSSION

These results are in agreement with the findings observed in low-volume systems.[2,10] Concerns for preventing additional cases of legionnaires' disease in patients at the hospital obviated any consideration of using one of the hot water circuits as an untreated, contemporaneous control for the ionization studies. Nevertheless, it is unlikely that any factor other than the ionization system was responsible for the near elimination of *L. pneumophila*. *L. pneumophila* was present in the hospital's hot water plumbing system at least 2 years before initiation of any treatment (data not shown) and persisted despite thermal treatment. The effect of the ionization system was prompt, lasted for at least 22 months, and was observed in three separate water circuits. After the implementation of the ionization system, no additional cases of legionellosis have been recognized at the hospital in the presence of active case surveillance involving routine culturing of bronchoalveolar lavage specimens for *Legionella* species.

Our findings suggest that copper-silver ionization is superior to thermal treatment for controlling *L. pneumophila* in high-volume hot water plumbing systems in hospitals. Of the three control measures (i.e., thermal treatment, hyperchlorination, and copper-silver ionization) that are often used to control *L. pneumophila* in hospital plumbing systems, copper-silver ionization appears to be the most efficacious at this time. Thermal treatment is labor intensive, has a potential for scalding, and must be applied at periodic and undefined intervals to maintain control.[7] It is unlikely that a significant improvement in the control of *L. pneumophila* would have been achieved in our study by extending the time that the heated water was allowed to sit in the pipes before flushing and by extending the rinsing times. These measures would not be expected to prevent the recolonization of the system by *L. pneumophila* that was observed when thermal treatment was discontinued. Hyperchlorination is expensive in terms of equipment and maintenance, is corrosive to plumbing system components, and may generate carcinogenic byproducts.[7] In contrast, the copper-silver ionization system is relatively easy and inexpensive to maintain. For a typical 250- to 300-bed hospital with two hot water circuits, a system costs about $60,000, and the maintenance cost for replacement of electrodes is about $7000 every 30 months (G. Lyslo, LiquiTech, Inc., personal communication, October 1996).

Relatively high concentrations of copper and silver can accumulate in sediment at the bottom of the hot water tanks in comparison with their concentrations in water obtained from the distal sites. The high levels in the sediment may contribute to the effectiveness of copper-silver ionization in high-volume plumbing systems by inhibiting *L. pneumophila* multiplication in the hot water tanks.[17-20] We found that silver levels were higher in samples from hot water tanks that did not yield *L. pneumophila* (median of 135 PPB from 21 samples) than in those that contained *L. pneumophila* (median of 26 PPB from three samples) ($p = 0.01$); copper levels were also higher in the samples that did not yield *L. pneumophila* (median of 1055 PPB) than in those that contained *L. pneumophila* (median of 332 PPB), but this difference was not statistically significant ($p > 0.5$). A potential problem with sediments that contain high concentrations of copper and silver is that the sediments could be dislodged from the bottom of hot water tanks during periods of high demand for hot water, leading to periodic bursts of copper and silver concentrations that exceed EPA standards at distal sites. However, only elevated silver levels (110 to 140 PPB) and not elevated copper levels were found in 1.9% of the hot water samples that were obtained from distal sites. Future studies should evaluate the efficacy of periodic withdrawal of sediment from hot water tanks to prevent copper and silver levels from exceeding EPA standards at distal sites while maintaining effective control of *L. pneumophila* throughout the hot water system.

The long-term efficacy of copper-silver ionization (i.e., >2 years) is not yet known. It is possible that legionellae may develop or acquire resistance to copper and silver ions, thereby diminishing the effectiveness of ionization. Copper and silver resistance occurs in other bacteria found in water and soil environments.[9] The long-term health effects from exposure of patients and hospital staff to copper and silver are also not yet known. Silver is not considered a mutagen or carcinogen, but chronic exposure to silver can result in argyria, a blue-gray discoloration of skin and organs.[16] Copper in drinking water is considered a health risk at levels above 1300 PPB and has caused gastrointestinal irritation (i.e. nausea, vomiting, and diarrhea).[21] Systemic toxic effects including liver and kidney damage have occurred from ingestion of exceptionally high doses of copper sulfate related to attempted suicide.[22] However, none of the water samples obtained from faucets in this study contained copper levels that exceeded the EPA standard. Levels of silver that only occasionally and slightly exceed the EPA limit probably do not represent a significant health risk, especially because minimal ingestion of hot water is expected to occur in the hospital setting. However, cold water intended for drinking passes through distal sites, where it may mix with deposits of copper and silver or with hot water containing copper and silver. For example, we found that all 16 cold water samples obtained from distal sites during the initial 12-month follow-up period contained 5 to 140 PPB of copper and 1 to 30 PPB of silver (results not shown in Fig 2).

In hospitals in which ionization is chosen, a monitoring and maintenance program must be developed to ensure effectiveness. The manufacturer's directions for monitoring and cleaning the electrodes must be followed. In addition to monitoring copper levels, as recommended by the manufacturer, routine monitoring of silver levels is also recommended because levels of silver can exceed the EPA standard when levels of copper do not. When levels of copper or silver in samples obtained from distal sites approach the EPA limits, appropriate adjustments should be made in the voltage applied to the flow cells. Finally, as with any system used to control *L. pneumophila* in hospital plumbing systems, monitoring *L. pneumophila* in distal sites and in hot water tanks is important. This monitoring is presently done at our hospital every 6 months in accordance with suggested guidelines.[23]

We recommend copper-silver ionization for controlling *L. pneumophila* in high-volume hot water plumbing systems implicated as a source of legionellosis or as a preventive measure before the onset of an outbreak.

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