



Efficacy of point-of-entry copper–silver ionisation system in eradicating *Legionella pneumophila* in a tropical tertiary care hospital: implications for hospitals contaminated with *Legionella* in both hot and cold water

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Summary A medical centre in Southern Taiwan experienced an outbreak of nosocomial Legionnaires' disease, with the water distribution system thought to be the source of the infection. Even after two superheats and flush, the rate of *Legionella* positivity in distal sites in hospital wards and intensive care units (ICUs) was 14% and 66%, respectively. Copper–silver ionisation was therefore implemented in an attempt to control *Legionella* colonisation in both hot- and cold-water systems. Environmental cultures and ion concentration testing were performed to evaluate the efficacy of ionisation. When the system was activated, no significant change in rate of *Legionella* positivity in the hospital wards (20% vs baseline of 30%) and ICUs (28% vs baseline of 34%) of the test buildings over a three-month period was found, although all *Legionella* positivity rates were below 30%, an arbitrary target for Legionnaires' disease prevention. When ion concentrations were increased from month 4 to month 7, however, the rate of *Legionella* positivity decreased significantly to 5% (mean) in hospital wards ($P = 0.037$) and 16% (mean) in ICUs ($P = 0.037$). *Legionella* positivity

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was further reduced to 0% in hospital wards and 5% (mean) in ICUs while 50% sites were still positive for Legionella in a control building. Although Legionella was not completely eradicated during the study period, no culture- or urine-confirmed hospital-acquired Legionnaires' disease was reported. Ionisation was effective in controlling Legionella for both hot and cold water, and may be an attractive alternative as a point-of-entry systematic disinfection solution for Legionella.

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Introduction

The major source for hospital-acquired Legionnaires' disease is the potable water system, though outbreaks of hospital-acquired Legionnaires' disease have rarely been reported from Taiwan. We first reported a large outbreak of hospital-acquired Legionnaires' disease, in which *Legionella pneumophila* serogroup 6 in the hospital water supply was responsible.¹ *L. pneumophila* serogroups 1, 6, 7, 10 were isolated from both hot- and cold-water faucets in the hospital water system. We also documented that two attempts of superheat-and-flush failed to control the Legionella colonisation in our institution. Furthermore, the replacement of the faucets and showerheads in the intensive care units (ICUs) did not have any effect on minimising the Legionella colonisation.¹ An effective long-term disinfection for controlling Legionella from both hot and cold water was therefore needed for prevention of hospital-acquired Legionnaires' disease.

The efficacy of copper–silver ionisation in eradicating Legionella from hospital water distribution systems has been well documented by many investigators worldwide.^{2–7} A multi-hospital survey also documented the efficacy and the robustness of copper–silver ionisation in 16 US hospitals for a period of 5–11 years.⁸ Ionisation has been recommended as the best available technology for control of Legionella in hospital hot-water systems.⁹

Most reports document that ionisation systems were installed at hot-water recirculating systems in hospitals. No publication has documented the efficacy of ionisation in which the ionisation system is installed at the point of entry to treat a large volume of both hot and cold water. Furthermore, the maximum allowable level for silver in drinking water is 0.05 mg/L in Taiwan. This limit may compromise the efficacy of ionisation, for which the manufacturers recommend a silver level of 0.02–0.08 mg/L.

Thus, we conducted a prospective study to evaluate the efficacy of ionisation for eradication

of Legionella in a large tertiary care medical centre in Kaohsiung, Taiwan.

Methods

Study hospital

The study hospital is a 1266-bed medical centre, located in Kaohsiung, Taiwan, which provides a full range of medical services and transplantation programmes for kidney, heart, lung and bone marrow. The hospital consists of three buildings: Building A, a clinical building (nine stories and a basement) including all patient wards and intensive care units (ICUs); Building B, an outpatient building (four stories and a basement) including clinics and offices for outpatient services; Building C, an emergency building (six stories with basement) including the emergency department and a Burn ICU.

Water distribution systems

All buildings in the study hospital used chlorinated domestic water, consuming ~1200 m³ of water per day. There are four water storage tanks, built at the point of entry. Buildings A and B were supplied from three underground 500 m³ water storage tanks which were interconnected to each other. Building C was supplied from a separate 250 m³ water storage tank. Buildings A and B were the test buildings for ionisation. Building C was the control building without ionisation.

Ionisation system

Three copper–silver ionisation systems (LiquiTech Inc., Bolingbrook, IL, USA) were installed at the water storage tanks that supplied Buildings A and B. Each system contained a flow through chamber that housed eight electrodes made from specially formulated copper–silver alloy. Each chamber was

connected to a pump that recirculated water through a 500 m³ storage tank. The output current was set at 4 A/60 V. The electrodes were cleaned twice a month to prevent scale accumulation on the surface of electrodes.

The release of copper and silver ions was controlled by a controller with solid-state micro-processor circuitry. From month 1 to month 6, the controller was set at continuous mode which the ionisation chamber was supplied at 4 A continuous. From month 7 to month 12, the controller was set at 'Copper Analyzer' mode. An on-line copper analyser (colorimeter) (APA 6000 Copper Analyzer, Hach USA, Loveland, CO, USA) was attached to the controller to measure copper ion concentration in water storage tanks. The analyser measured the copper concentration and the value was relayed to the controller that regulated the current automatically to increase or decrease the ion production to meet the target ion concentration in the storage tanks.

Environmental monitoring for Legionella

Twenty-five distal sites (21 in test buildings, four in the control building) were cultured for Legionella. The swab samples were taken from the culture sites before the ionisation start-up, monthly for the first six months and bi-monthly thereafter. Historical baseline cultures showed that 50% (3/6) of distal sites were positive for *L. pneumophila*. The most recent baseline cultures before activation of ionisation were 32% (6/19) and 50% (2/4) distal site positive for Legionella at test buildings and the control building, respectively.

We followed the standardised culture method for *L. pneumophila* that has been documented elsewhere.⁸ Suspected colonies were subcultured in parallel onto buffered charcoal yeast extract (BCYE) and blood agar plate (BAP) media. Colonies that grew after subculture on BCYE medium but not on BAP were tested with a latex test (Oxoid Ltd, Basingstoke, Hants, UK) and confirmed using a DFA monoclonal antibody (Monoclonal Technologies, Inc., Alpharetta, GA, USA). Isolates categorised as *L. pneumophila* serogroup 1 on the latex test were confirmed using a polyvalent *L. pneumophila* serogroup 1 antibody; isolates categorised as *L. pneumophila* serogroup 2–14 were confirmed with a monovalent *L. pneumophila* individual serogroup antibody; and Legionella-like organisms were tested with monovalent *L. micdadei* antibody.

Monitoring of ion concentration

Copper and silver ion concentrations were validated twice a month for the months 1, 2, 3,

monthly for the months 4, 5, 6, and bi-monthly thereafter by an inductively coupled plasma–optical emission spectrophotometer (Perkin–Elmer, Waltham, MA, USA).

Statistical analysis

The Legionella positivity and ion concentration results from test (hospital wards and ICUs) and control buildings were compared using *t*-test (two-sample, assuming unequal variances) by Microsoft Excel.

Results

When the ionisation system was activated, the copper/silver ion concentrations at distal sites of hospital wards were 0.094/0.020, 0.114/0.014 and 0.110/0.007 mg/L at months 1, 2 and 3, respectively. During this period, there was no significant change in the rate of Legionella positivity in hospital wards [20% (mean) vs baseline of 30%] although all rates of Legionella positivity were below 30%, an arbitrary target for Legionnaires' disease prevention. The copper/silver ion concentrations were increased significantly to 0.143/0.008, 0.157/0.011, 0.180/0.017 and 0.212/0.014 mg/L at months 4, 5, 6 and 7 ($P=0.027$). Rate of Legionella positivity decreased significantly to 5% (mean) vs 20% from month 3 ($P=0.019$) (Figure 1). Legionella positivity was further reduced to 0% while 50% sites were still positive for Legionella in the control building. After month 7, no Legionella was found in water from the hospital wards.

Whereas ionisation was successful in eradicating Legionella in hospital wards, it did not achieve the same efficacy in the ICUs. When the ionisation system was activated, the copper/silver ion concentrations at distal sites of ICUs were 0.076/0.012, 0.087/0.008 and 0.086/0.011 mg/L at months 1, 2 and 3, respectively. During this period, there was no significant change in rate of Legionella positivity in the ICUs [28% (mean) vs baseline of 34%] although it was below 30%. The copper/silver ion concentrations were increased to 0.132/0.005, 0.052/0.014, 0.091/0.013 and 0.115/0.010 mg/L at months 4, 5, 6 and 7. Rate of Legionella positivity decreased to 16% (mean) vs 40% from month 3 ($P=0.020$) (Figure 1). Legionella positivity was further reduced to 5% while 50% sites were still positive for Legionella in the control building. Although this reduction of Legionella positivity was statistically significant ($P=0.02$), Legionella was not

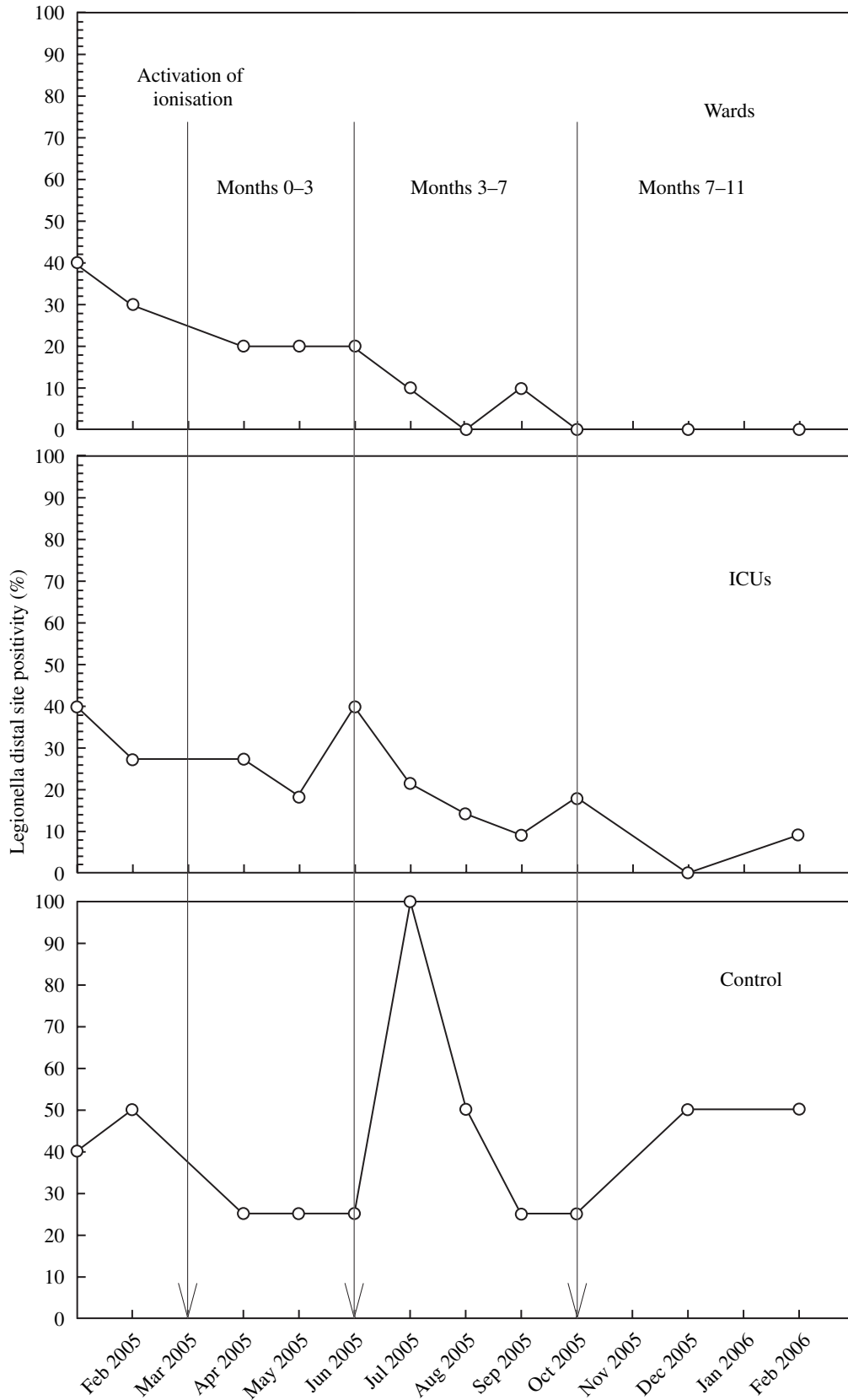


Figure 1 Distal site positivity of Legionella in the study hospital water distribution system. ICUs, intensive care units.

completely eradicated and one distal site in ICUs remained positive.

When we compared the difference in rate of *Legionella* positivity and ion concentrations between ICUs and hospital wards in the test building, we found that the mean copper ion concentration in ICUs (0.094 mg/L) was significantly lower than that in hospital wards (0.145 mg/L) ($P=0.0012$) (Table I). Mean silver ion concentration in ICUs (0.0124 mg/L) was lower than that in hospital wards (0.0192 mg/L) but no significant difference was found ($P=0.439$) (Table I). Further investigation found that the water from an on-site purification system using a reverse osmosis process was mixed with the tap water in ICUs. This on-site purification system was first designed 17 years ago to provide purified water for the ICUs. However, after several renovations and plumbing modifications, the waterlines of the purification system had been partially connected with the tap-water lines in ICUs by mistake. This may explain the low ion concentrations found in the ICUs.

It was noteworthy that the size of the electrodes was 50% smaller than the original at month 3. After examination, the vendor determined that the electrodes had been eroded due to the high shear velocity of the water flow by the recirculating pumps, not due to the electrolytic consumption of the electrodes. A bypass valve was installed in each recirculating loop that only allowed 50% of the water through the ionisation chamber while the remaining 50% was through the bypass loop. This implementation reduced the erosion of the electrodes substantially.

Discussion

Disinfection of hospital water system for *Legionella* is a well-established infection control practice to prevent hospital-acquired Legionnaires' diseases. Our previous effort of superheat-and-flush had failed to control *Legionella* colonisation.

Copper–silver ionisation was chosen because of its advantages over the conventional modalities.⁹

Most copper–silver ionisation installations in the USA and Europe were installed only onto the hot-water systems because *Legionella* prefers a warm environment in which to reproduce; the temperature of cold water (<10 °C) is unfavourable. However, the ambient temperature in Taiwan, an island with subtropical temperatures, is high, so cold-water temperature can easily exceed 30 °C during the summertime. Our environmental surveillance showed that cold water lines were also colonised with *Legionella*. Thus, both hot- and cold-water systems needed disinfection. The most economical way to treat both hot and cold water was to install a disinfection system at the point of entry. Four months after the copper–silver ionisation system was activated, a significant decline on the rate of *Legionella* positivity was observed (Figure 1). After one year of evaluation, the rate of *Legionella* positivity in hospital wards and ICUs of the test buildings was 0% (0/10) and 9% (1/11), respectively, compared to the control building of 50% (2/4). Although *L. pneumophila* was not completely eradicated during this one year study period, no case of hospital-acquired Legionnaires' disease was reported from the hospital-acquired infection surveillance.

Direct ingestion of ions from water is a major concern. Since most ionisation installations in the USA and Europe were only in hot-water systems, direct consumption of ions via hot water was minimal. Releasing metallic ions into drinking water was not appealing to the hospital administrators. A copper–silver ionisation system installation was approved, but the ion concentration applied into the water system was predetermined. The target ion concentrations for copper and silver were set at 0.2 and 0.02 mg/L, respectively, which are the lowest concentrations (0.2–0.8 mg/L for copper; 0.02–0.08 mg/L for silver) recommended by the manufacturers and others.^{10,11} This was a compromise between

Table I Change in copper and silver ion concentrations (mg/L) during the disinfection period

	Month									
	1	2	3	4	5	6	7–8	9–10	11–12	
Ward										
Copper	0.0942	0.1141	0.1094	0.1430	0.1570	0.1800	0.2120	0.1480	0.1447	
Silver	0.0192	0.0155	0.0065	0.0075	0.0110	0.0170	0.0140	0.0120	0.0128	
Intensive care unit										
Copper	0.0757	0.0866	0.0860	0.1315	0.0515	0.0905	0.1145	0.1160	0.0940	
Silver	0.0124	0.0080	0.0108	0.0050	0.0140	0.0130	0.0095	0.0215	0.0118	

effectiveness of ionisation and the potential health hazards to the patients and employees of the hospital. Nevertheless, significant decline of Legionella positivity was achieved at copper and silver ion concentrations (mean copper: 0.16 mg/L; silver: 0.014 mg/L) below the recommended levels. Our finding confirmed a previously published study that the successful control of hospital-acquired Legionnaires' disease was achieved at suboptimal ion concentrations below recommended level.² The 58% distal site colonisation rate (baseline) of Legionella was reduced to 17% after the installation of copper–silver ionisation at mean copper concentration of 0.25 mg/L in cold water and 0.08 mg/L in hot water (silver data not reported).²

Copper–silver ionisation is a relatively new disinfection technology in Asia. The local vendor's knowledge and technical support would be an important factor for its success. We chose an American vendor who has a local distributor in Taiwan. Though it was their first sale and installation of an ionisation system in Taiwan, we found their system expertise and technical support to be highly satisfactory. The distributor detected a problem with erosion of electrodes and was able to fix it using a simple and low-cost bypass valve.

The weakness of this study was that we did not intensively screen every hospital-acquired pneumonia for Legionnaires' disease. The link between reduction of Legionella positivity in hospital water systems and the reduction of hospital-acquired Legionnaires' disease has been well established.^{12–14} We decided to focus on the environmental surveillance for Legionella which was more economical. Infectious disease physicians would make their request on the clinical specimens to include Legionella testing based on their evaluation as a routine hospital-acquired pneumonia monitoring programme in the hospital. During the study period, 122 clinical specimens were tested for Legionella and none of them yielded a positive result.

In conclusion, copper–silver ionisation was effective in eradicating Legionella for both hot and cold water at the point-of-entry installation. A significantly reduced rate of Legionella positivity in test buildings was achieved in the study hospital. Copper–silver ionisation may be an attractive alternative as a point-of-entry systematic disinfection solution for Legionella. Our results may be useful for hospitals in regions where both hot and cold-water systems are colonised with Legionella. To our knowledge, this is the first report that has documented the efficacy of ionisation at

point-of-entry installation for control of Legionella in hospitals for both hot and cold water.

Conflict of interest statement

None declared.

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References

1. Chen YS, Liu YC, Lee SS, *et al.* Abbreviated duration of superheat-and-flush and disinfection of taps for *Legionella* disinfection: lessons learned from failure. *Am J Infect Control* 2005;**33**:606–610.
2. Biurrun A, Caballero L, Pelaz C, Leon E, Gago A. Treatment of a *Legionella pneumophila*-colonized water distribution system using copper–silver ionization and continuous chlorination. *Infect Control Hosp Epidemiol* 1999;**20**:426–428.
3. Colville A, Crowley J, Dearden D, Slack RC, Lee JV. Outbreak of Legionnaires' disease at University Hospital, Nottingham. *Epidemiology, microbiology and control. Epidemiol Infect* 1993;**110**:105–116.
4. Kusnetsov J, Iivanainen E, Elomaa N, Zacheus O, Martikainen PJ. Copper and silver ions more effective against legionellae than against mycobacteria in a hospital warm water system. *Water Res* 2001;**35**:4217–4425.
5. Rohr U, Senger M, Selenka F. Effect of silver and copper ions on survival of *Legionella pneumophila* in tap water. *Zentralbl Hyg Umweltmed* 1996;**198**:514–521.
6. Mietzner S, Schwille RC, Farley A, *et al.* Efficacy of thermal treatment and copper–silver ionization for controlling *Legionella pneumophila* in high-volume hot water plumbing systems in hospitals. *Am J Infect Control* 1997;**25**:452–457.
7. Lee JV, Surman SB, Kirby A, Seddon F. Eleven years of experience with novel strategies for Legionella control in a large teaching hospital. In: Marre R, Bartlett C, Cianciotto NP, Fields BS, Frosch M, Hacker J, Luck PC, editors. *Legionella*. Washington, DC: American Society for Microbiology; 2002. p. 398–401.
8. Stout JE, Yu VL. Experiences of the first 16 hospitals using copper–silver ionization for *Legionella* control: implications for the evaluation of other disinfection modalities. *Infect Control Hosp Epidemiol* 2003;**24**:563–568.
9. Lin YS, Stout JE, Yu VL, Vidic RD. Disinfection of water distribution systems for *Legionella*. *Semin Respir Infect* 1998;**13**:147–159.
10. Landeen LK, Yahya MT, Gerba CP. Efficacy of copper and silver ions and reduced levels of free chlorine in inactivation of *Legionella pneumophila*. *Appl Environ Microbiol* 1989;**55**:3045–3050.
11. Liu Z, Stout JE, Tedesco L, *et al.* Controlled evaluation of copper–silver ionization in eradicating *Legionella pneumophila* from a hospital water distribution system. *J Infect Dis* 1994;**169**:919–922.

12. 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 for control of nosocomial legionnaires' disease and Pittsburgh pneumonia. *Lancet* 1983;2:307–310.
13. Yu VL, Stout JE. Hospital characteristics associated with colonization of water systems by *Legionella* and risk of nosocomial legionnaires' disease: a cohort study of 15 hospitals. *Infect Control Hosp Epidemiol* 2000;21:434–435.
14. Fiore AE, Butler JC, Emori TG, Gaynes RP. A survey of methods used to detect nosocomial legionellosis among participants in the National Nosocomial Infections Surveillance System. *Infect Control Hosp Epidemiol* 1999;20:412–416.