CONCISE COMMUNICATION

Safety and Efficacy of Chlorine Dioxide for *Legionella* Control in a Hospital Water System

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In a 30-month prospective study, we evaluated the efficacy of chlorine dioxide to control *Legionella* organisms in a water distribution system of a hospital with 364 patient beds and 74 skilled nursing beds. The number of hot water specimens positive for *Legionella* organisms decreased from 12 (60%) of 20 to 2 (10%) of 20. An extended time (18 months) was needed to achieve a significant reduction in the rate of *Legionella* positivity among hot water specimens. At the time of writing, no cases of hospital-acquired Legionnaires disease have been detected at the hospital since the chlorine dioxide system was installed in January 2003. Use of chlorine dioxide was safe, based on Environmental Protection Agency limits regarding maximum concentrations of chlorine dioxide and chlorite.

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In the United States, the efficacy and safety of injecting chlorine dioxide in water systems to prevent hospital-acquired Legionnaires disease has not been extensively evaluated.[1-3] Our previous field study showed that an extended time (1.75 years) was required for complete eradication of *Legionella* organisms from a hospital water distribution system and that the residual concentration of chlorine dioxide in the hot water system was significantly lower than that in the cold water system.[1] This hospital had a large secondary distribution system that included a 2.3×10^6-L (520,000-gallon) reservoir and 23 buildings across 60 acres. We hypothesized that the efficacy of chlorine dioxide for controlling *Legionella* organisms might be improved for a hospital with a smaller secondary distribution system in which the chlorine dioxide is injected into the incoming water main. The objectives of this study were to evaluate the efficacy of chlorine dioxide for control of *Legionella* organisms in a hospital with a smaller secondary water distribution system and to determine whether the residual levels of chlorine dioxide and its by-product, chlorite, would exceed Environmental Protection Agency limits.

METHODS

Setting. After a case of healthcare-acquired legionellosis due to *Legionella pneumophila* was diagnosed in the hospital, chlorine dioxide was selected to disinfect the hospital water system. The hospital has 2 buildings, each with 8 floors. Water is supplied by the city water department. Since October 2002, *Legionella* organisms have been detected in the hot water systems of both buildings. The percentage of hot water outlets positive for *Legionella* organisms was 67% (6 of 9 outlets) before installation of the chlorine dioxide generation system. The system was installed and operational in January 2003.

Chlorine dioxide generation system. One chlorine dioxide generation unit (Halox) was installed in each building by employees of the Environmental Hygiene Services division of Nalco. Electrochemical cassettes generate approximately 500 mg/L of chlorine dioxide solution from sodium chlorite. The chlorine dioxide is injected into the incoming cold water main at a target concentration of 0.5-0.7 mg/L, depending on the flow rate of the incoming cold water.

Sample collection. Samples were obtained for *Legionella* detection from 13 sites in building 1 and 7 sites in building 2, located on the second, fourth, fifth, sixth, and eighth floors. Hot and cold water samples were collected from distal outlets (ie, sinks and showers). Samples from the hot water storage tanks (or recirculation line) in each building were also obtained. Water samples of 120 mL for *Legionella* culture were collected immediately after the outlet tap was turned on. Sampling was originally scheduled to occur every 2 months between August 2003 and June 2005 but was extended through February 2006. Tests for detection of *Legionella* organisms were performed at the Special Pathogens Laboratory (Pittsburgh, PA), as described elsewhere.[1]

After the distal outlets were flushed for 1 minute, water samples were collected for chlorine dioxide analysis. Temperature measurements were taken directly from the flow stream after the flush. Levels of chlorine dioxide were analyzed in both hot and cold water samples, using the Hach Method 10101 DPD Method for chlorine dioxide (0.00-5.00 mg/L) with a glycine reagent and the DPD Free Chlorine reagent (Hach). The colorimetric measurements were performed with the DR/2010 Spectrophotometer (Hach). A 10-mL sample was taken for chlorine dioxide analysis at the time of collection. Glycine was used to eliminate the interference of free chlorine. Hospital personnel also monitored residual chlorine dioxide levels in cold water throughout the distribution system, using a pocket colorimeter and the DPD method.

Seven hot water samples and 5 cold water samples were collected for chlorite analysis every 2 months from 5 locations in building 1 and 2 locations in building 2. Samples were sparged with nitrogen gas for 10 minutes to remove residual chlorine dioxide and filtered through a 0.2-μm filter. Then 50 mg/L of ethylenediamine was added to each sample. The chlorite concentration was measured by ion chromatography (DX-500; Dionex) with a suppressor and conductivity detector, according to Environmental Protection Agency method 300.1.[4]

Statistical analysis. Stata, version 9.0 (Stata), was used for statistical analysis. The significant differences were evaluated by means of Student *t* tests and analysis of variance.

RESULTS

The number of hot water specimens positive for *Legionella* organisms decreased from 12 (60%) of 20 in August 2003 to 2 (10%) of 20 in February 2006 ($P < .05$) (Figure 1). An extended period (18 months) was needed to achieve this reduction, because of initially low residual chlorine dioxide levels in hot water, which increased significantly from 0.04 mg/L in August 2003 to 0.11 mg/L in February 2006 ($P < .05$). Fewer than 20% of cold water specimens tested positive for *Legionella* organisms; during the study period, the residual level of chlorine dioxide in cold water increased from 0.3 to 0.5 mg/L ($P > .05$).

Although the rate of *Legionella* positivity among specimens obtained at distal sites decreased during the study period, we did not observe a statistically significant decrease in the concentration of *Legionella* organisms in positive specimens ($P > .05$). At the time of writing, no cases of hospital-acquired Legionnaires disease have been detected at the hospital since the chlorine dioxide system was installed in January 2003.

The mean temperature of hot water at distal sites was 44°C (range, 27°C-52°C) during the study period. The mean temperature of cold water at distal sites was 18°C (range, 4°C-31°C). The mean chlorite level in 91 hot water samples was 0.42 mg/L, and the mean chlorite level in 65 cold water samples was 0.28 mg/L.

DISCUSSION

Healthcare facilities are increasingly faced with the decision of choosing a *Legionella* disinfection method.[5] Elsewhere, we recommended that such systems undergo a 4-step evaluation process to ensure safety and efficacy.[6] This study represents step 3 of the process for chlorine dioxide: a controlled prospective study in an individual hospital.

We found that *Legionella* positivity in hot water samples decreased from 60% in August 2003 to 10% in February 2006 ($P < .05$) (Figure 1). We believe this finding can be explained by the significant increase in the residual concentration of chlorine dioxide, from 0.04 mg/L in August 2003 to 0.11 mg/L in February 2006.

The percentage of hot water samples that tested positive for *Legionella* organisms unexpectedly increased from 10% in December 2004 to 45% in February 2005. No malfunction of the chlorine dioxide generator was reported before this increase, and the mean residual concentration of chlorine dioxide remained at 0.36 mg/L in December 2004 and February 2005. The reason for this increase remains unclear. The feed concentration of chlorine dioxide was increased to 0.58 mg/L in building 1 in April 2005. Samples collected in April and June 2005 showed that the percentage of *Legionella*-positive samples decreased to 25% (Figure 1).

After the chlorine dioxide system was installed, a significant decrease in the percentage of hot water specimens that tested positive for *Legionella* organisms was observed. However, an extended period (duration, 18 months) was needed to achieve this reduction. This observation is consistent with the findings of Sidari et al.,[1] who reported that 1.75 years were needed to

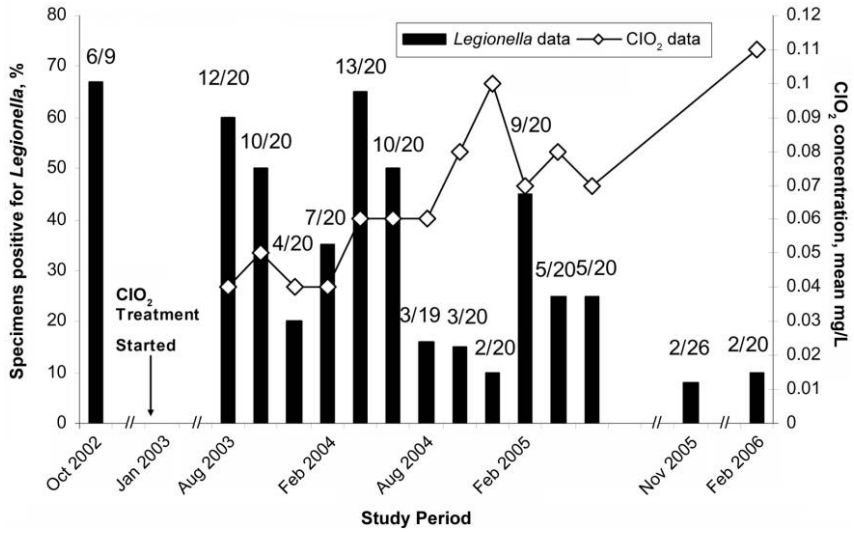

FIGURE 1. Percentage of specimens positive for *Legionella* organisms and concentration of chlorine dioxide in hot water samples. A significant reduction in the rate of *Legionella* positivity among hot water specimens was observed after the first 18 months of chlorine dioxide treatment ($P < .05$, by analysis of variance). Ratios denote the number of *Legionella*-positive hot water specimens/number of specimens tested.

eliminate *Legionella* organisms from the water systems they studied. Sidari et al.[1] speculated that the injection of chlorine dioxide into the 2.3×10^6-L (520,000-gallon) reservoir and its subsequent distribution throughout a large campus may have contributed to the prolonged lag time. In the present study, chlorine dioxide was injected into the incoming cold water main of a comparatively smaller secondary distribution system. Given that we observed a lag time similar to that observed by Sidari and colleagues, the delayed reduction in the rate of *Legionella* positivity is more likely caused by the low residual concentration of chlorine dioxide in the hot water.

It is clear that maintaining a sufficient residual level of chlorine dioxide in the hot water system is challenging. An elevated water temperature hastens the conversion of chlorine dioxide to chlorite by the reactions with organic compounds in the water distribution system.[7] This finding is consistent with our observation that the mean chlorite concentration in hot water was higher than that in cold water.

The percentage of samples positive for *Legionella* organisms decreased significantly when the residual levels of chlorine dioxide in hot water specimens were at least 0.10 mg/L ($P < .05$, by analysis of variance) (Figure 2). In the water distribution system at this hospital, the mean residual chlorine dioxide concentration seldom reached 0.10 mg/L, which may explain the extended time needed to accomplish a significant reduction in the rate of *Legionella* positivity among water specimens. Increasing the residual concentration of chlorine dioxide to 0.1 mg/L at distal outlets in a hot water system might improve the efficacy of chlorine dioxide in controlling *Legionella* organisms.

Previous field studies on the efficacy of chlorine dioxide for controlling *Legionella* organisms in the water systems of European hospitals showed that at least 6 months of continuous injection of chlorine dioxide was required for complete eradication of or significant reduction in the percentage of samples testing positive for the organism.[6-10] A field study on the efficacy of chlorine dioxide in European hospitals also reported that *Legionella* organisms persisted in significant concentrations (up to 20,000 cfu/L) and with little reduction in the number of *Legionella*-positive hot water and cold water specimens after 2 years of 0.5 mg/L chlorine dioxide injections.[10] Our results show that *Legionella* organisms can be suppressed in cold water when the residual concentration of chlorine dioxide is 0.30-0.50 mg/L. This finding is consistent with results of other studies.[1-3]

It may be possible to improve the efficacy of chlorine dioxide by performing "shock treatment" (ie, by temporarily increasing the chlorine dioxide concentration to more than 0.8 mg/L, which is the limit recommended by the Environmental Protection Agency).[3] Makin[11] reported that the successful use of chlorine dioxide for controlling *Legionella* organisms in a hot water system required increasing the chlorine dioxide level to 3-5 mg/L. Daily flushing of sinks and showers in patient rooms may also improve the efficacy of this agent.[2] However, both of these measures need to be evaluated in a controlled study.

Another possible approach to achieving higher residual levels of chlorine dioxide in hot water includes injecting chlorine dioxide at a point in the water system after the hot water tanks. This approach may shorten the time needed to achieve measurable residual levels of chlorine dioxide at distal outlets. The impact of injecting chlorine dioxide directly into hot water has yet to be evaluated for *Legionella* control.

The Environmental Protection Agency has determined that the safest maximum residual levels of chlorine dioxide and chlorite are 0.8 mg/L and 1.0 mg/L, respectively. The residual levels of chlorine dioxide and chlorite at distal outlets in the water system of our hospital were below these limits. Users of chlorine dioxide systems must comply with current reg-

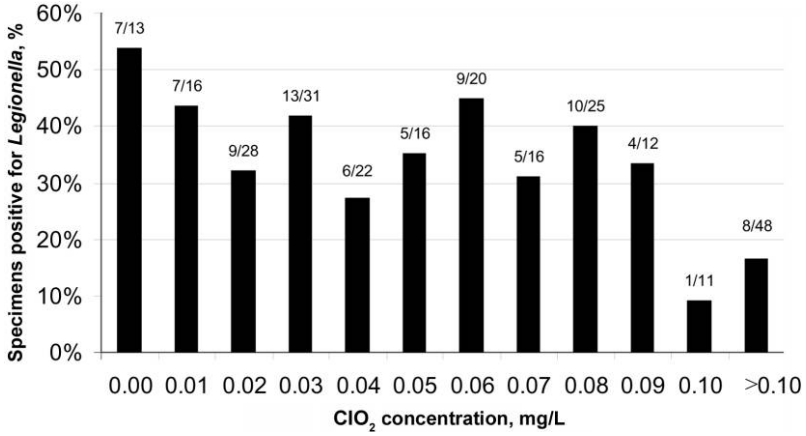

FIGURE 2. Effect of the chlorine dioxide concentration on the percentage of hot water specimens positive for *Legionella* organisms. The percentage of samples positive for *Legionella* organisms decreased significantly when the residual levels of chlorine dioxide in hot water specimens were at least 0.10 mg/L ($P < .05$, by analysis of variance). Ratios denote the number of *Legionella*-positive hot water specimens/number of specimens tested.

ulations for municipal water systems. This compliance involves daily monitoring of chlorine dioxide levels and monthly monitoring of chlorite levels. Our data suggest that less frequent monitoring of chlorite levels in a hospital with a small secondary water system would be sufficient to satisfy safety concerns.

A significant reduction in the percentage of hot water samples positive for *Legionella* organisms was achieved using chlorine dioxide treatment. Chlorine dioxide did not completely eliminate *Legionella* organisms from the hospital's hot and cold water system, given a target feed concentration of 0.5-0.7 mg/L in the cold water. However, this and other studies have demonstrated that elimination of *Legionella* organisms is not necessary to prevent hospital-acquired Legionnaires disease.[6]

Until the optimal operating parameters for chlorine dioxide are delineated, we recommend that regular environmental monitoring for *Legionella* organisms must be performed, all patients with hospital-acquired pneumonia should be screened for Legionnaires disease and treated empirically for Legionnaires disease if the cause is unknown, and other methods for *Legionella* control (eg, periodic use of heat flush methods or installation of point-of-use filters in high-risk areas) should be instituted in the first 6-12 months of operation or until a sustained low rate of *Legionella* positivity (ie, less than 30%) among water specimens is consistently achieved.

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