A 17-MONTH EVALUATION OF A CHLORINE DIOXIDE WATER TREATMENT SYSTEM TO CONTROL *LEGIONELLA* SPECIES IN A HOSPITAL WATER SUPPLY

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ABSTRACT

OBJECTIVE: To assess the safety and efficacy of a chlorine dioxide water treatment system in controlling *Legionella* in a hospital water supply.

DESIGN: For 17 months following installation of the system, we performed regular water cultures throughout the building, assessed chlorine dioxide and chlorite levels, and monitored metal corrosion.

RESULTS: Sites that grew *Legionella* species decreased from 41% at baseline to 4% (P = .001). *L. anisa* was the only species recovered and it was found in samples of both hot and cold water. Levels of chlorine dioxide and chlorite were below Environmental Protection Agency (EPA) limits for these chemicals in potable water. Further, enhanced carbon filtration effectively removed the chemicals, even at chlorine dioxide levels of more than twice what was used to treat the water. After 9 months, corrosion of copper test strips exposed to the chlorine dioxide was not higher than that of control strips. During the evaluation period, there were no cases of nosocomial *Legionella* in the building with the system, whereas there was one case in another building.

CONCLUSIONS: Our results indicate that operation of a chlorine dioxide system effectively removed *Legionella* species from a hospital water supply. Furthermore, we found that the system was safe, as levels of chlorine dioxide and chlorite were below EPA limits. The system did not appear to cause increased corrosion of copper pipes. Our results indicate that chlorine dioxide may hold promise as a solution to the problem of *Legionella* contamination of hospital water supplies (*Infect Control Hosp Epidemiol* 2003;24:575-579).

Legionella species remain an important cause of nosocomial pneumonia. The true incidence of nosocomial infections is not known; however, some series have demonstrated that *Legionella* species can account for up to 30% of nosocomial pneumonias.[1,2] Despite increased awareness of and advances in the treatment of these infections, the mortality rate for nosocomial *Legionella* pneumonia remains in the range of 35% to 40%.[3,4] Furthermore, cases of nosocomial legionnaires' disease can be a source of negative publicity and litigation for hospitals because these infections are generally believed to be preventable. Because the natural habitat of these organisms is water, they are widespread in institutional water systems. Culture surveys of various hospitals have found that up to 70% of hospital water supplies in some areas are contaminated with *Legionella*.[5] These infections are likely to become an even more significant problem as immunosuppressive treatments, a major risk for nosocomial legionnaires' disease,[6] become more common.

The association between contamination of the hospital water supply and nosocomial cases has been well demonstrated and is further supported by the fact that in a group of hospitals where *Legionella* could not be isolated from the water supply, no nosocomial cases were found despite intensive surveillance.[7] This association has prompted a great deal of interest in exploring methods for controlling *Legionella* in hospital water supplies. Currently, several methods are available for this purpose, including superheating (thermal eradication), ultraviolet light, copper–silver ionization, hyperchlorination, chloramines, ozone treatment, and chlorine dioxide.[8] Although hot water systems have long been regarded as the primary reservoirs for these organisms, there is growing evidence to suggest that contamination of potable (drinking or cold) water systems may be an even more important risk for nosocomial infections.[9,10] Thus, there is growing interest in evaluating the efficacy and safety of these methods for the treatment of both hot and potable water supplies in hospitals. The construction of a new building at our hospital gave us the opportunity to evaluate the safety and efficacy of chlorine dioxide for control of *Legionella* in the healthcare setting.

Chlorine dioxide is approved by the Environmental Protection Agency (EPA) for use as a potable water disinfectant under federal law.[11] The chemical is a gas that is generated mechanically or electrolytically from a sodium chlorite solution. Sodium chlorite is approved by the EPA for use in generating chlorine dioxide as a potable water

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disinfectant. Chlorine dioxide is a potent oxidant and kills bacteria via oxidative disruption of cellular processes.[12] Although it has been used for many years in industrial and municipal water systems,[12-15] there have not been many reports on the use of chlorine dioxide to remove *Legionella* from hospital water supplies. However, the limited published experience suggests it is efficacious.[16,17]

METHODS

Background

The Weinberg building of the Johns Hopkins Hospital is a 154-bed facility that houses surgical and oncology patients, including bone marrow transplant patients. In addition to general patient care floors and an intensive care unit, the building also has 16 operating rooms as well as surgical pathology, laboratory, and sterile processing facilities. Patients undergo hemodialysis in the building. Because this patient population has well-recognized risk factors for nosocomial *Legionella* infections[1] and because of historic problems with *Legionella* in the hospital water system, when construction plans were made it was decided that a water treatment system would be installed.

After reviewing available data on currently available systems, we chose chlorine dioxide as the water treatment system. A major consideration was that chlorine dioxide does have EPA approval as a disinfectant for potable water. A chlorine dioxide system (Halox Inc., Bridgeport, CT) was installed on the potable water main after it enters the building. This water main then splits to provide both the potable and the hot water for the building. There are two semi-instantaneous hot water generators that provide hot water to the building. Installation of the water system was completed in March 2000, but it was used minimally until the building was occupied in September 2000.

Microbiologic Monitoring

Samples of both hot and cold water were taken from 28 faucets throughout the building on a regular basis. Sites were chosen to assess all patient care floors in both clinical and nonclinical areas where faucets were used both frequently and infrequently. In each room, the tap was opened and allowed to run for 60 seconds before the sample was collected. For each sample collected, a direct culture and a concentrated culture were performed.

The direct culture consisted of placing 100 µL of water directly onto three separate plates of selective media for *Legionella*. The three plates used contained buffered charcoal-yeast extract (BCYE) with polymyxin B, anisomycin, and vancomycin; BCYE with dye, glycine, vancomycin, and polymyxin B; and BCYE *Legionella* selective agar (vancomycin, colistin, and anisomycin) (Becton Dickinson, Sparks, MD). The concentrated culture consisted of passing 50 mL of the original sample through a polycarbonate filter (Whatman, VWR Scientific, West Chester, PA). The filter was then placed into 5 mL of the original, unfiltered sample and vortexed. Next, 100-µL aliquots were placed onto each of the three plates. All plates were incubated in CO_2 at 37°C within a moist chamber for 7 days. Colonies suggestive of *Legionella* were subcultured on blood agar and BCYE plates. Organisms that grew on BCYE but not on blood agar were identified as *Legionella* species and were then speciated using direct fluorescent antibody reagents (m-TECH, Alpharetta, GA) and the gas liquid chromatography Sherlock Microbial Identification System (MIDI Inc., Newark, DE).

Monitoring of Chlorine Dioxide, Chlorite, and Chlorate Levels

Levels of chlorine dioxide residuals were analyzed from both hot and cold water samples from one site at the main and on the first, fourth, and fifth floors using N, N-Diethyl-p-phenylenediamine chemistry measured with spectrophotometric methods. Disinfection by-products, chlorite and chlorate, were evaluated using ion chromatography and amperometric titration methods adapted from the EPA.[18]

To ensure optimal performance of hemodialysis and laboratory equipment, carbon filtration was enhanced to remove chlorine dioxide and its by-products. Before the building was occupied, various levels of chlorine dioxide were introduced into the system to measure chlorine dioxide, chlorate, and chlorite levels following passage through various carbon filters. Water for hemodialysis machines passed through two external carbon filters (Norit, acid/washed, low fines granular activated carbon; Norit Americas Inc., Atlanta, GA), whereas water for the laboratory equipment passed through one external filter (Neu-Ion OA6 carbon tank, Neu-Ion Inc., Baltimore, MD).

Once the chlorine dioxide system was activated for continuous operation, chlorine dioxide levels were monitored continuously to ensure that they did not exceed 0.8 ppm. Additionally, after the system was activated, levels of chlorine dioxide and chlorite were assessed throughout the building. Chlorate levels were not assessed as often as chlorite and chlorine dioxide levels were because there are no current EPA standards for chlorate levels in potable water.

Monitoring of Corrosion

Corrosion of water pipes was monitored using standard copper and mild steel coupon test strips that were inserted into the pipes both upstream and downstream of the treatment system, with the upstream coupon test strip serving as a control. Corrosion was measured after 9 months of operation of the system by removing the test strips and weighing them. The decrease in weight is converted to a corrosion rate, reported in milliliters per year (MPY).

Surveillance for Legionella

Our hospital performs active clinical surveillance for *Legionella* infections. All bronchoalveolar lavage samples taken from inpatients who have evidence of a lower respiratory tract infection are routinely cultured for *Legionella*. All cultures that grow *Legionella* and all posi-

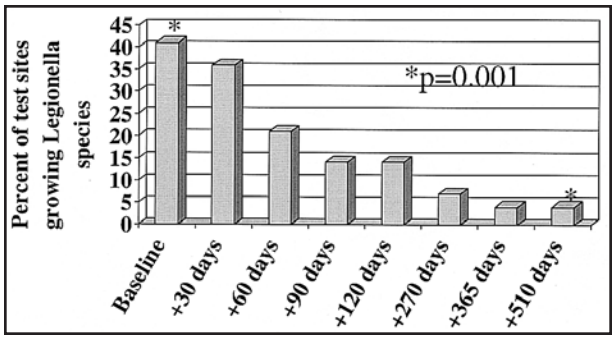

FIGURE 1. Percent of test sites that grew *Legionella* species during the evaluation of the chlorine dioxide system. The decrease from 41% to 4% was statistically significant ($P = .001$).

tive urinary antigens are reviewed by infection control staff to determine whether the case is nosocomial. Patients who have culture-confirmed *Legionella* infections up to 9 days after admission are considered "possible" nosocomial cases, and any patient who has a confirmed infection more than 9 days after admission is considered a "definite" nosocomial case. Any case in which the patient's isolate matches an environmental sample by pulsed-field gel electrophoresis is considered a definite nosocomial case, regardless of the incubation period.

RESULTS

Microbiologic Results

For the 17 months following activation of the system, *Legionella* in cultured water declined steadily from 41% of all sites tested at baseline to 4% ($P = .001$) (Fig. 1). Only *L. anisa* was recovered and it was cultured from both the hot and the cold water systems. After 17 months, the only remaining test site that grew *Legionella* was on the fifth floor of the building, farthest away from the chlorine dioxide source.

Chlorine Dioxide, Chlorite, and Chlorate Levels

Although the system was designed to implement a maximum chlorine dioxide level of 0.8 ppm, before the building was occupied, levels as high as 2.0 ppm were introduced to test the efficacy of carbon filtration systems. Samples of filtered water from the hemodialysis machines were free of chlorite and chlorate ions, even with chlorine dioxide concentrations of 2.0 ppm. The only exception was a single reading of a chlorate level of 0.07 ppm when the overall chlorine dioxide level was 1.3 ppm. However, this reading was actually below the calibrated lower limit of detection of the instruments of 0.1 ppm and thus may have been spurious. Likewise, samples of the filtered water from the laboratory equipment were free of chlorate and chlorite ions at chlorine dioxide concentrations as high as 1.6 ppm. Again, the lone exception was an isolated chlorate level of 0.08 ppm when the overall chlorine dioxide level was 1.4 ppm (Table).

Following 1 month and 17 months of operation, chlorine dioxide and chlorite levels were assessed throughout the building. The system had been set to achieve a maximum chlorine dioxide level of 0.8 ppm and this was indeed the measured level at the main treatment point. Chlorine dioxide levels did not exceed the EPA maximum residual disinfectant level goal of 0.8 ppm and chlorite levels did not exceed the EPA maximum contaminant level goal of 1.0 ppm. After 1 month, levels were higher on lower floors of the building, but this difference was not present after 17 months (Fig. 2).

TABLE
EFFICACY OF CARBON FILTERS IN REMOVING CHLORITE AND CHLORATE FROM WATER TREATED WITH VARIOUS LEVELS OF CHLORINE DIOXIDE

	Chlorine Dioxide (ppm)	Chlorite (ppm)	Chlorate (ppm)
Hemodialysis sample			
External carbon filter	0.6	0.0	0.0
External carbon filter	0.8	0.0	0.0
Internal filter	1.3	0.0	0.07*
Internal filter	1.6	0.0	0.0
Reverse osmosis membrane	2.0	0.0	0.0
Laboratory sample			
External carbon filter	0.85	0.0	0.0
External carbon filter	1.2	0.0	0.0
Internal filter	1.4	0.0	0.08*
Reverse osmosis membrane	1.6	0.0	0.0

*Indicates result outside of the calibration range of the testing equipment (lower calibrated limit = 0.1 ppm).

Monitoring of Corrosion

After 9 months of operation, corrosion of the untreated potable water copper coupon test strip was measured at 0.4 MPY, compared with 0.3 MPY for the potable water coupon test strip that was exposed to chlorine dioxide. Corrosion of the untreated potable water mild steel coupon test strip was 3.9 MPY, compared with 5.6 MPY for the potable water mild steel coupon test strip that was exposed to chlorine dioxide.

Surveillance for Nosocomial Legionella

No cases of nosocomial *Legionella* infection were detected in the building with the chlorine dioxide system during the 17-month evaluation. During that time, there was one definite case of nosocomial *Legionella* pneumonia in a building without a water treatment system.

DISCUSSION

To our knowledge, this is the first study of the efficacy and safety of a chlorine dioxide system in a U.S. healthcare facility. Our experience confirms the limited published data from Europe supporting the efficacy of

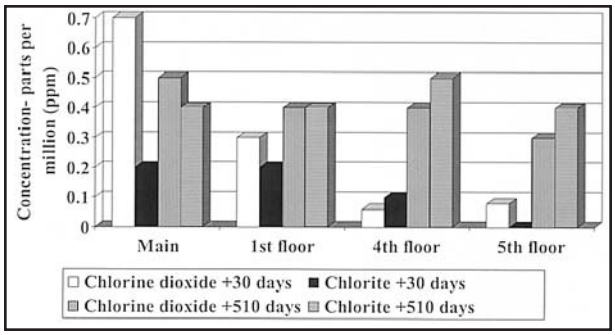

FIGURE 2. Concentrations of chlorine dioxide and chlorite at various locations throughout the building after 30 and 510 days of operation of the system. At 30 days, levels were higher at the main than on the first and upper floors; however, this difference had decreased markedly by day 510.

chlorine dioxide in eradicating *Legionella* species from hospital water supplies.[16,17] Seventeen months of continuous operation of such a system in one building at our institution has nearly eradicated *Legionella* from the building's water supply. The only site that has remained contaminated is on the top floor of the building, farthest from the treatment source.

Our results were obtained with the system operational only Monday through Friday from 7 am to 7 pm, when water demand was adequate to operate the system. We did not employ "chlorine dioxide (ClO_2) shock treatments," where the building is exposed to high levels of chlorine dioxide. Furthermore, we did not establish a protocol to ensure that all of the distal taps were opened on a regular basis, but simply relied on normal use of the taps to expose them to ClO_2-treated water. Given our results, we believe that the *Legionella* might have been eradicated more rapidly if the taps had been accessed more often. *Legionella* species are known to reside in biofilms in pipes and flow-restrictive devices (eg, faucet aerators). Although in vitro data suggest that chlorine dioxide can penetrate these films, this penetration is hindered by decreased exposure of the biofilms to the chlorine dioxide as would happen in distal taps that were used infrequently. A protocol to open taps, especially on the upper floors, might have helped the system reach equilibrium more quickly, which would have increased the exposure times of the pipes on the upper floors to the chlorine dioxide.

Operation of the system appeared to be safe based on current federal regulations governing acceptable levels of chlorine dioxide and chlorite. The Code of Federal Regulations states that the maximum residual disinfectant level goal of chlorine dioxide should not exceed 0.8 ppm and that the maximum contaminant level goal of chlorite should not exceed 0.8 ppm in drinking water.[19] We found that by using the maximal concentration of chlorine dioxide at the main water source, the levels of chlorine dioxide and chlorite that occupants of the building were exposed to were well below the maximum allowable levels. In fact, even at the fixture closest to the treatment main, the sum of chlorine dioxide and chlorite was below 0.8 ppm in half of the measurements that were taken. Currently, there are no regulations governing the levels of chlorate ions that are allowed in drinking water; however, in our experience, chlorate levels never exceeded 0.4 ppm.

We found that soon after the system was activated, chlorine dioxide and chlorite levels were much higher at fixtures that were closest to the main. However, with time, the building reached equilibrium, and at 17 months there were no differences in the chlorine dioxide and chlorite levels between the fixtures that were closest to the main and the fixtures that were farthest away from the main.

Pipe corrosion remains a major concern with any water treatment system, especially in older buildings. The use of a chlorine dioxide system seemed to have no deleterious effects on the building's plumbing system. The plumbing system is primarily a copper one and, after 9 months of continuous operation of the chlorine dioxide system, we noted no significant corrosion in the copper coupon test strips. We did note slightly higher corrosion rates in the mild steel coupon test strips that were exposed to chlorine dioxide compared with the control strips, but it is not clear that this difference was significant. Our results regarding corrosion are in accordance with those of Hood et al.,[17] who reported no problems with corrosion after 6 years of use of a chlorine dioxide system in a hospital with an old plumbing system.

The potent oxidizing capacities of chlorine dioxide and chlorite have raised concerns about the potential for these compounds to cause hemolysis in those who are particularly vulnerable to oxidative stress. Indeed, animal and human studies have shown that oxidative hemolysis on exposure to these chemicals is up to four times more likely in red blood cells that are G6PD deficient.[20,21] Thus far, however, limited studies in community dialysis centers using water treated with chlorine dioxide have failed to demonstrate any adverse effects.[22,23] We found that we were able to address these potential concerns with the addition of two extra carbon filters to the dialysis equipment, which removed all of the chlorine dioxide and chlorite, even at supratherapeutic levels of chlorine dioxide. Likewise, carbon filters were used to remove the chemicals from the water supply to sensitive laboratory equipment.

A major limitation of our study was the short duration of the evaluation. Although our initial results are encouraging, we cannot yet comment on long-term efficacy. In one study of a copper–silver ionization system, the results in the initial year were similarly encouraging, but the efficacy diminished after 3 years of operation[24]; whether that will happen with chlorine dioxide remains to be seen. However, the 6-year experience with chlorine dioxide from the Glasgow Royal Infirmary has been promising.[17] Another limitation was that continuous field monitoring of chlorine dioxide and chlorite levels was not performed, and thus it is theoretically possible that the maximum levels were exceeded at times when no testing was being done. However, this seems highly unlikely

because the chlorine dioxide system has safety features that automatically turn off the unit to prevent the level of chlorine dioxide in the water from exceeding 0.8 ppm.

As the hospitalized population becomes older and sicker, the risks for nosocomial *Legionella* infections will only increase. Further, some states are considering legislation that will require healthcare institutions to develop *Legionella* control plans that will include the performance of regular water cultures. Thus, interest in water treatment systems for hospitals is likely to continue to grow. Unfortunately, there is not enough extensive, long-term experience to suggest that any one of these systems is clearly superior to the others. Thus, it is crucial that institutions using these systems report their experiences. We believe that our experience with chlorine dioxide indicates that this system may hold promise as a solution to the problem of *Legionella* contamination of hospital water supplies.

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