ORIGINAL ARTICLE

Electronic-Eye Faucets: *Legionella* Species Contamination in Healthcare Settings

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(See the commentary by Zingg and Pittet, on pages 241–242.)

OBJECTIVE. To compare heterotrophic plate counts (HPCs) and *Legionella* species growth from electronic and manual faucet water samples.

DESIGN. Proportions of water samples with growth and colony-forming units were compared using Fisher's exact test and the Wilcoxon rank-sum test, respectively.

SETTING. Two psychiatric units and 1 medical unit in a 1,000-bed university hospital.

METHODS. Water samples were collected from 20 newly installed electronic faucets and 20 existing manual faucets in 3 hospital units. Manual faucets were located in rooms adjacent to the electronic faucets and received water from the same source. Water samples were collected between December 15, 2008, and January 29, 2009. Four electronic faucets were dismantled, and faucet components were cultured. *Legionella* species and HPC cultures were performed using standard methods.

RESULTS. Nearly all electronic faucets (19/20 [95%]) grew *Legionella* species from at least 1 water sample, compared with less than half (9/20 [45%]) of manual faucets ($P = .001$). Fifty-four (50%) of 108 electronic faucet water cultures grew *Legionella* species, compared with 11 (15%) of 75 manual faucet water cultures ($P < .001$). After chlorine dioxide remediation, 4 (14%) of 28 electronic faucet and 1 (3%) of 30 manual faucet water cultures grew *Legionella* species ($P = .19$), and 8 (29%) electronic faucet and 2 (7%) manual faucet cultures had significant HPC growth ($P = .04$). All 12 (100%) of the internal faucet components from 2 electronic faucets grew *Legionella* species.

CONCLUSIONS. Electronic faucets were more commonly contaminated with *Legionella* species and other bacteria and were less likely to be disinfected after chlorine dioxide remediation. Electronic faucet components may provide points of concentrated bacterial growth.

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Nontouch electronic-eye faucets are increasingly used in healthcare settings to lower water consumption, reduce costs, and theoretically reduce recontamination of healthcare workers' hands. However, there are currently no data that support a decrease in rates of colonization or healthcare-associated infections associated with the use of electronic faucets. Previous studies have found higher rates of bacterial contamination associated with electronic faucets than with manual handle-operated faucets[1-7] and minimal success at decontamination by standard procedures.[3-5] These studies primarily evaluated bacterial contamination with *Pseudomonas aeruginosa*, and less is known about the possible contamination of electronic faucets with *Legionella* species, a cause of healthcare-associated pneumonia in immunocompromised patients. Previous studies have implicated tap water as a source of healthcare-associated infections, and one linked an outbreak of *Mycobacterium mucogenicum* bacteremia to contaminated electronic faucets.[7-11] Therefore, higher rates of bacterial contamination of electronic-eye faucets could have significant implications for at-risk patients in healthcare settings.

A new model of electronic-eye faucet (Figure 1) selected for installation in a new clinical building was installed for evaluation in 20 patient care areas in the existing hospital in 2008. This evaluation was part of a larger evaluation of the performance and maintenance of newly installed electronic faucets. The aim of this portion of the evaluation was to compare bacterial contamination of tap water from newly installed electronic faucets with that from existing manual faucets (Figure 2). The efficacy of the city's municipal chlorine treatment and the hospital's chlorine dioxide disinfection of the faucets was also assessed.

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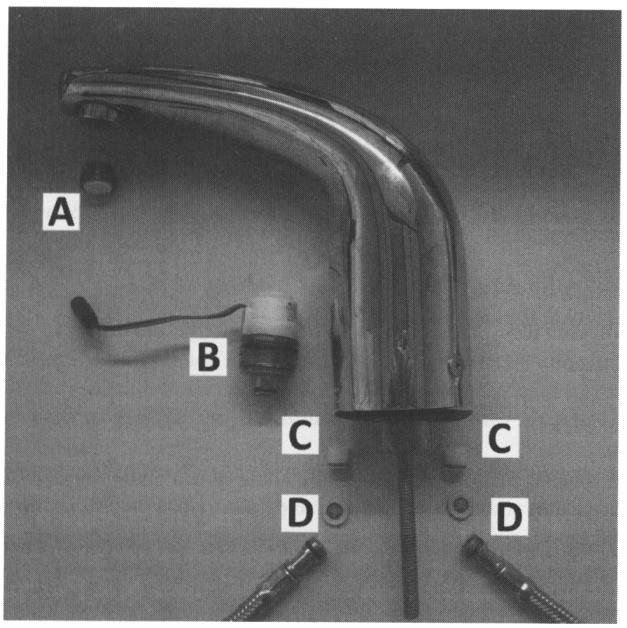

FIGURE 1. Disassembled electronic-eye faucet. *A*, Aerator; *B*, solenoid valve; *C*, check valve; *D*, inline filter. A color version of this figure is available in the online edition of the journal.

METHODS

Setting

Johns Hopkins Hospital is a 1,000-bed, tertiary-care, academic hospital in Baltimore, Maryland. This evaluation was part of a larger evaluation of the "hygiene flush" mode on newly installed electronic faucets. The hygiene flush mode was set to automatically flush water through the electronic faucet for 3 minutes every 12 hours and to record the number of times the faucet was activated and used. Electronic faucets were programmed to operate for 1 minute once activated, utilizing 0.5-gpm (gallons per minute) aerators. Hot and cold water was mixed in electronic faucets, and the faucets were set to maintain a water temperature of 35°C (95°F), which was confirmed at installation. Manual faucets utilized a 2.2-gpm aerator.

Water samples were originally collected from 20 electronic faucets and 5 manual faucets; however, once bacterial contamination of electronic faucets was detected, sampling was expanded to include 15 additional manual faucets. The 20 electronic and 20 manual faucets sampled were located in patient rooms in 3 units (2 psychiatric and 1 medical) in 2 buildings. Each hospital unit had an equal number of electronic and manual faucets evaluated. Electronic and manual faucets were located in adjacent rooms and received water from the same central pipe system.

Chlorine concentration in city water entering the hospital averaged between 0.2 and 0.4 ppm (parts per million) during the evaluation period. Cold and hot water systems at Johns Hopkins Hospital are continuously treated with chlorine dioxide as part of the hospital's waterborne pathogen control program. Chlorine dioxide levels are maintained at an average concentration of 0.5 ppm. Chlorine, chlorine dioxide, and associated by-product levels of chlorite are monitored daily to meet Environmental Protection Agency and Maryland Department of Environment regulations.

Microbiologic Sampling

Water samples were collected on 7 days over a 6-week period (Figure 3) between December 15, 2008, and January 29, 2009. Coincidentally, 2 disruptions in the city water supply to our facility occurred at the beginning of the evaluation. These disruptions involved a decrease in city water pressure entering the hospital as well as a decrease in chlorine concentration of incoming city water. Both types of interruptions are known to introduce and increase the amount of detectable bacteria in potable-water distribution systems. In response to the water system disruptions, chlorine dioxide remediation (5.0 ppm for 6 hours) was performed on January 12 (Building A) and 13 (Building B). To further investigate the etiology, extent, and specific location of contamination seen in water cultures from electronic faucets, 4 electronic faucets were removed and internal components were cultured, including inline filter assemblies, check valve assemblies, solenoid valve assemblies, aerator assemblies, and aerator gaskets. Heterotrophic plate counts (HPCs) and *Legionella* species cultures were performed on water samples and on swab samples from electronic faucet internal components.

To simulate clinical conditions, first-draw water samples were collected without flaming or disinfecting outlets. Electronic faucet first-draw samples were blended hot and cold water, and manual faucet first-draw samples were hot water. Water temperature was not measured on first-draw water samples from either type of faucet because stagnant water in the faucets and supply piping would have been at ambient room temperature. Samples were collected aseptically in sterile 250-mL bottles. HPCs of water samples and electronic faucet internal components were conducted using standard methods.[12] HPCs of 500 colony-forming units (CFUs)/mL or greater were considered significant.

Legionella species cultures were performed using direct culture and concentrated culture methodology. Direct cultures were performed by plating 100 μL of water directly onto buffered charcoal yeast extract (BCYE) agar and BCYE selective media with DGVP (dye, glycine, vancomycin, and polymixin B; Becton Dickenson). For concentrated cultures, 100 mL of the original water sample was filtered through a 0.2-μm polycarbonate filter (Whatman; VWR Scientific), resuspended in 10 mL of the original unfiltered water sample, and vortexed, and 100-μL aliquots were subsequently plated onto BCYE agar and BCYE with DGVP agar. All plates were incubated at 37°C for 7 days. Candidate colonies were tested using latex agglutination followed by direct fluorescent antibody staining (m-TECH) to confirm the presence of *Le-*

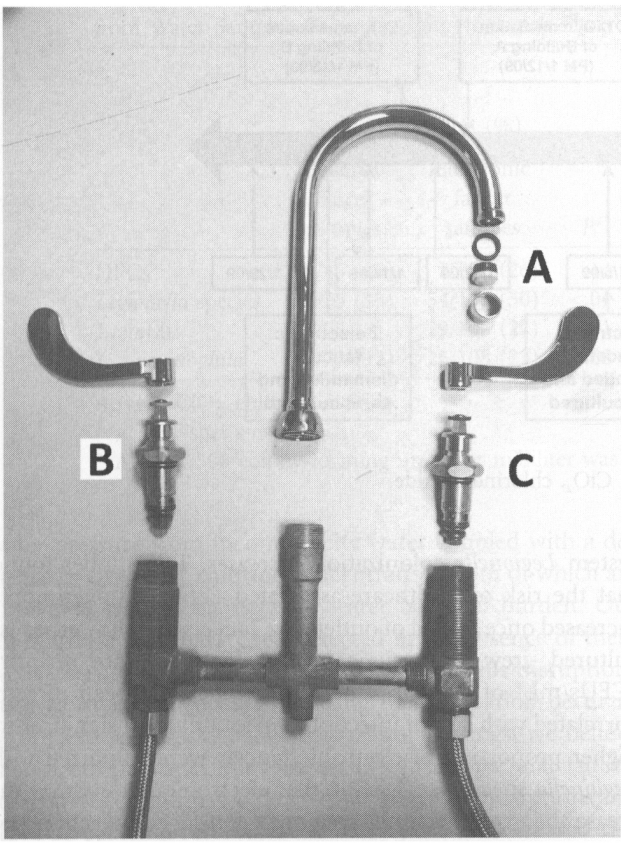

FIGURE 2. Disassembled manual faucet. *A*, Aerator; *B*, hot water compression cartridge; *C*, cold water compression cartridge. A color version of this figure is available in the online edition of the journal.

gionella species. *Legionella* species identified included *L. pneumophila* and *L. anisa*. All cultures were performed at the Special Pathogens Laboratory (Pittsburgh, Pennsylvania).

Statistics

To compare differences in proportions, the χ^2 or Fisher's exact test was used. Nonparametric continuous variables were compared using the Wilcoxon rank-sum test. Two-tailed *P* values less than or equal to .05 were considered statistically significant.

RESULTS

A total of 183 water samples were collected, 108 from electronic faucets and 75 from manual faucets. *Legionella* species cultures were performed on each water sample, and HPCs were performed on a subset of water samples during the first, fifth, sixth, and seventh weeks (58 from electronic faucets and 45 from manual faucets; Table 1). Fifteen (26%) of 58 water samples from electronic faucets had significant bacterial growth on HPC, compared with 6 (13%) of 45 water samples from manual faucets ($P = .14$). A greater proportion of electronic faucets had significant growth on HPC from any one water sample throughout the evaluation, compared with manual faucets (13/20 [65%] vs 5/20 [25%], respectively; $P = .02$). Median colony counts on HPC were higher in water samples from electronic faucets than in water samples from manual faucets (275 vs 30 CFUs/mL; $P = .02$). After chlorine dioxide remediation, water samples from electronic faucets were more likely to show continued significant bacterial growth on HPC (8/28 [29%] for electronic vs 2/30 [7%] for manual; $P = .04$).

Both direct and concentrated *Legionella* cultures were performed with results based on the method yielding the highest absolute CFUs per milliliter. *Legionella* species were more frequently isolated from electronic faucet water samples than from samples from manual faucets (54/108 [50%] vs 11/75 [15%]; $P < .001$). Nearly all electronic faucets (19/20 [95%]) grew *Legionella* species from at least 1 water sample, compared with less than half (9/20 [45%]) of manual faucets ($P = .001$). There was no significant difference in median *Legionella* species colony counts between electronic and manual faucets (10 vs 5 CFUs/mL; $P = .99$). We directly compared recovery rates of *L. pneumophila*, the species most commonly associated with human disease, and found that a greater proportion of electronic faucets grew *L. pneumophila*, compared with manual faucets (13/20 [65%] vs 7/20 [35%]; $P = .11$). Although not statistically significant, a greater proportion of electronic faucet water samples continued to grow *Legionella* species after chlorine dioxide remediation (4/28 [14%] vs 1/30 [3%]; $P = .19$], and a greater proportion of electronic faucets continued to grow *Legionella* species from any one water sample after chlorine dioxide remediation than manual faucets (3/16 [19%] vs 1/20 [5%]; $P = .30$).

A total of 25 internal components were cultured from 4 electronic faucets; 2 faucets were removed and cultured before chlorine dioxide remediation, and 2 were removed and cultured after remediation. All 12 internal components grew *L. pneumophila* before chlorine dioxide remediation, and 9 of 12 had significant growth on HPC. After chlorine dioxide remediation, 2 of 13 internal components grew *L. pneumophila*, and 62% (8/13) of components had significant HPC growth. Two check valves (cold and hot water) had continued *L. pneumophila* growth after remediation. No cases of *Legionella* infection were detected during the evaluation period. Water samples obtained from cold and hot water supply pipe mains before, during, and after the study did not grow *Legionella*.

Electronic faucet operational data (stored electronically) showed that faucets were used between 8 and 110 times in a 24-hour period. The scheduled hygiene flush was never triggered on any electronic faucet during the evaluation period due to frequent use. There was no difference in frequency of electronic faucet use between patient units. On the basis of frequency of use, a programmed run time of 1 minute per use, and the use of 0.5-gpm aerators, electronic faucets used between 4 and 55 gallons of water per 24-hour period. Assuming that manual faucets were used with similar frequency

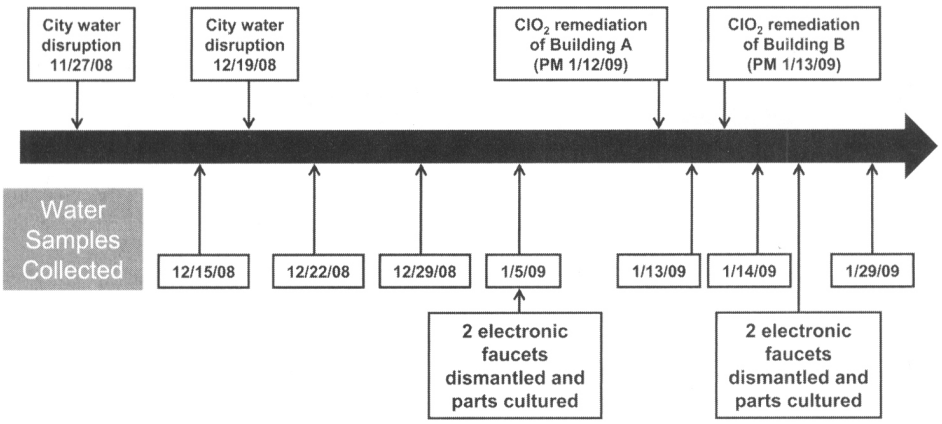

FIGURE 3. Evaluation timeline. ClO_2, chlorine dioxide.

and duration but with 2.2-gpm aerators, manual faucet water use was between 17.6 and 242 gallons of water per 24-hour period.

DISCUSSION

Nontouch electronic faucets are becoming more common in healthcare settings as a way to reduce water use and to theoretically improve hand hygiene by preventing recontamination of hands when touching faucet handles. However, we found that nontouch electronic faucets were more likely to become contaminated with bacteria, including *L. pneumophila*, than manually operated faucets. We also found a trend toward continued higher rates of bacterial contamination of electronic faucets after chlorine dioxide remediation, suggesting that electronic faucets may be more difficult to disinfect with standard procedures. All electronic faucet internal components tested in this evaluation grew *L. pneumophila*, with some components showing continued growth of *L. pneumophila* after chlorine dioxide remediation. In addition, the internal components of electronic faucets exhibited significant HPC bacterial growth before and after chlorine dioxide remediation, again suggesting an inability to fully disinfect electronic faucets.

Previous studies have also found higher rates of bacterial contamination of electronic faucets.[1-6,13] Only one of these studies[2] cultured water samples for *Legionella* species, and it found that 100% (10/10) of electronic faucets grew *Legionella* species, compared with 30% (3/10) of manual faucets. Our findings supplement these data, as we included more samples and performed extensive culturing of the internal components of electronic faucets to better investigate the source of bacterial contamination.

There is a well-established association between contamination of a healthcare system's water supply and risk of healthcare-associated *Legionella* pneumonia,[10,14,15] with mortality ranging from 35% to 40%.[16,17] The risk of healthcare-associated *Legionella* infection increases as the extent of water system *Legionella* colonization increases. Two studies found that the risk of healthcare-associated *Legionella* pneumonia increased once a third of outlets (eg, faucets and showerheads) cultured grew *L. pneumophila*.[18,19] The absolute quantity (CFUs/mL) of *Legionella* per culture has not been directly correlated with risk of infection. We found that a significantly higher proportion of electronic faucets were colonized with *Legionella* species, suggesting that electronic faucets may increase the extent of water system *Legionella* colonization and pose an increased risk of healthcare-associated *Legionella* infections.

Previously hypothesized reasons for bacterial contamination of electronic faucets include (1) low water flow,[2,5] (2) retrograde contamination from the faucet outlet,[4] (3) tepid water temperature as a result of the mixing of hot and cold water,[2,5] (4) contamination during manufacturing,[13] and (5) bacterial colonization of internal magnetic valves.[2] We found growth of *L. pneumophila* and significant HPC growth from all internal components cultured, some of which continued to grow *L. pneumophila* after chlorine dioxide remediation. We monitored water usage during the evaluation period and found that providers frequently used electronic faucets. Therefore, we do not believe that disuse significantly contributed to bacterial contamination of the studied electronic faucets. On the basis of our findings, we suspect that both low water-flow rates and electronic faucet internal components made of rubber and polyvinyl chloride that provide surfaces that promote biofilm formation[20,21] contribute to bacterial contamination and to difficulty in decontaminating electronic faucets by standard methods.

This evaluation has several limitations. First, the investigation had a short follow-up period. It is possible that continued culturing for a longer time period might have demonstrated that routine water system treatment with chlorine dioxide was eventually able to disinfect electronic faucets. Second, differences in rates of bacterial colonization between electronic and manual faucets were detected after a loss of

TABLE 1. Frequency of Isolation of *Legionella* Species and Significant Heterotrophic Plate Count (HPC) Growth from Water Samples Collected from Nontouch Electronic Faucets and Manual Faucets

	Total, proportion (%)			Before ClO_2 remediation, no. (%)			After ClO_2 remediation, no. (%)		
	Manual faucet samples	Electronic faucet samples	P[a]	Manual faucet samples	Electronic faucet samples	P[a]	Manual faucet samples	Electronic faucet samples	P[a]
HPCs[b]	6/45 (13)	15/58 (26)	.14	4 (27)	7 (23)	1.0	2 (7)	8 (29)	.04
Legionella species	11/75 (15)	54/108 (50)	<.01	10 (22)	50 (63)	<.01	1 (3)	4 (14)	.19
L. anisa	2/75 (3)	29/108 (27)	<.01	1 (2)	26 (33)	<.01	1 (3)	3 (11)	.34
L. pneumophila	9/75 (12)	25/108 (23)	.08	9 (20)	24 (30)	.29	0 (0)	1 (4)	

NOTE. ClO_2, chlorine dioxide.

[a] χ^2 or Fisher's exact test.

[b] At least 500 colony-forming units per milliliter was considered significant.

water pressure from incoming city water coupled with a decrease in city water chlorine concentration, both of which are known to lead to increases in water bacterial burden. Our findings may not have been detected in the absence of these water-disruption events; however, water system disruptions such as those that occurred during this evaluation occur in healthcare settings. On the basis of our findings, we believe that electronic faucets are more likely than manual faucets to become contaminated during water system disruptions and serve as bacterial reservoirs that may pose an increased risk to susceptible patients. It has been hypothesized that tepid water produced by the mixing of hot and cold water in electronic faucets promotes bacterial growth and contributes to increased rates of contamination. We did not directly measure water temperatures from electronic and manual faucets; however, electronic faucets were set to maintain a water temperature of 35°C (95°F). We are unable to draw conclusions about the role of differences in water temperature. Last, no cases of *Legionella* infection were detected during the evaluation period; therefore, we are unable to comment on any direct associations between use of electronic faucets and increased risk of *Legionella* infection.

In conclusion, we found that electronic faucets were more likely to be contaminated with bacteria than manual faucets. Electronic faucets were more likely to exhibit continued growth of bacteria after chlorine dioxide remediation, suggesting difficulty with disinfection and a need for other methods and more extensive maintenance. Our findings suggest that the combination of low water-flow rates and internal components that may provide surfaces for biofilm formation and concentrated bacterial growth lead to higher rates of bacterial growth in water from electronic faucets. Our findings led to the removal of electronic faucets from clinical areas at Johns Hopkins Hospital and the decision to not install electronic faucets in new clinical areas that are under construction or being renovated until further information is available.

On the basis of our findings and evidence from previous studies, we recommend that infection prevention and control teams thoroughly evaluate the use of electronic faucets in clinical areas. If electronic faucets are currently in use, periodic monitoring of water samples for growth of *Legionella* species may be warranted, and consideration of removal of electronic faucets from at-risk patient care areas, such as bone marrow transplant units, may be warranted. Future research is needed to further investigate whether contamination of electronic faucets is associated with an increased risk of healthcare-associated infection. Finally, electronic and manual faucet design and evaluation standards need to be developed and regulated for healthcare environments.

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