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Sanitizing effectiveness of commercial "active water" technologies on *Escherichia coli* O157:H7, *Salmonella enterica* and *Listeria monocytogenes*

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ABSTRACT

Electrochemically activated water (ECAW), also known as electrolyzed water, and ozonized water are typically effective in inactivating bacteria, but their generation typically uses high current and voltage. A few simpler antimicrobial technologies that are also based on the application of a mild electrical current have been recently marketed to food retail and service customers claiming to have sanitizing properties for controlling bacteria. The objective of this study was to determine the sanitizing effect of some of these commercial technologies on *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Salmonella enterica* and compare them with sterile water, generated ECAW generated with a pilot size electrolyzing unit, and salt solutions sprayed using commercial device sprays. A concentration of 100 mg/L ECAW had sanitizing effects of at least 5 log CFU/mL reductions on liquid culture and more than 4 log CFU/coupon reductions for *E. coli* O157:H7, *L. monocytogenes* and *Salmonella* dried on stainless steel surface, respectively. No bacterial cells were detected by direct plate counting post-ECAW treatment. In contrast, the treatment of liquid cultures with any of the commercial technologies tested resulted in non-significant bacterial cell reductions greater than 0.5 log CFU/mL. Similarly, when cells had been dried on metal surfaces and treated with any of the water generated with those technologies, no reductions were observed. When the manufacturer's instructions were followed, the reduction of cells on surface was largely due to the physical removal by cloth-wiping after water fraction application. These results indicate that treatment with any of these portable technologies had no noticeable antimicrobial activity. These results would be helpful for guiding consumers when choosing a right sanitization to ensure food safety.

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1. Introduction

Escherichia coli O157:H7, *Salmonella* spp. and *Listeria monocytogenes* are three of the most important infectious bacteria targeted for reductions by the Centers for Disease Control and Prevention (CDC) (Matyas et al., 2010). *Salmonella* is the bacterial pathogen that causes most of the foodborne outbreaks and *L. monocytogenes* is one of the most deadly pathogens transmitted by food (CDC, 2011b; Purdue University, 2011). The detection of these bacteria cause most of the food recalls within the category of foodborne pathogen contamination (CDC, 2011a; USDA, 2011). Several foodborne disease outbreaks have been due to the contamination of industrially produced foods, but there could be and a range of raw foods that could also be contaminated in the domestic environment.

The transmission of these pathogens via unsanitary conditions during food preparation is quite possible. Microbial surveys of domestic kitchens have found significant contamination with a variety of bacterial microorganisms, including fecal coliforms, *E. coli,* and *Salmonella* (Redmond & Griffith, 2003). The source of contamination of kitchen surfaces can be multiple, but raw foods such as poultry and meats have been documented to spread some of these pathogenic bacteria. Proper cleaning and sanitizing of kitchen sites and food equipment is critical for preventing the spread of microorganisms and minimizing cross-contamination to ready-to-eat food via food preparation surfaces.

There is a variety of chemical sanitizers currently approved as direct-contact disinfectants for food preparation surfaces. However, the use of chemical compounds presents some issues related to disposal and worker's safety. Electrolyzed water and ozone are two alternative sanitizing technologies that generate the active oxidizing component on site and do not use toxic chemical substances. Electrochemically activated water (ECAW) is an electrolyzed water sanitizer used for food and food equipment, which uses electrolysis

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of dilute sodium chloride solutions generating two distinct fractions, catholyte and anolyte. The anolyte is the sanitizing fraction and contains different forms of chlorine including hypochlorous acid (Hricova, Stephan, & Zweifel, 2008). The ECAW's sanitizing effects depend on free available chlorine (FAC), oxidation-reduction potential (ORP) and pH.

The use of different types of electrolyzed water has been reported to be active to kill various foodborne pathogens including *E. coli* O157:H7, *Salmonella* and *L. monocytogenes* (Guentzel, Lam, Callan, Emmons, & Dunham, 2008). It has many advantages including the usage of safe source materials, safety for handling and distribution and being more environmentally-friendly compared to traditional chlorine sanitizers (Deza, Araujo, & Garrido, 2003, 2005, 2007; Kim, Hung, Brackett, & Lin, 2003). Its effectiveness is the result of a combination of different forms of chlorine with hypochlorous acid which contributes to a greater extent (Hricova et al., 2008).

Ozone (O_3) is a potent oxidant, formed from oxygen (O_2) by a high energy input. Commercially, ozone can be generated using different types of energy that include photochemical (i.e. ultraviolet radiation), electric discharge (i.e. corona discharge) chemical, thermal, chemonuclear, and electrolytic methods (Emer, Akbas, & Ozdemir, 2008; Karaca & Velioglu, 2007; Novak, Demirci, & Han, 2008). Ozone can be applied in gaseous or ozonated water for sanitizing (Pascual, Llorca, & Canut, 2007; Perry & Yousef, 2011). Ozone can be spontaneously decomposed into a nontoxic product, oxygen (Vurma, Pandit, Sastry, & Yousef, 2009), leaving no disinfectant residues (Karaca & Velioglu, 2007).

Ozone was approved as a disinfectant or sanitizer in food processing by FDA (Emer et al., 2008; Karaca & Velioglu, 2007). Treating food surfaces with ozone can be achieved either by adding gaseous ozone continuously or intermittently to the storage atmosphere throughout the storage period or by washing or dipping in ozonated water to prevent the spread of cross-contamination and inactivate the microbial cells (Emer et al., 2008; Hassenberg et al., 2007; Huang, Hung, Hsu, Huang, & Hwang, 2008; Mahmoud et al., 2004; Novak et al., 2008; Park, Hung, & Chung, 2004). Gaseous ozone concentration of 0.1 mg/L for 6 h was found to be appropriate to inactivate *E. coli* in whole and ground black peppers without alteration of the organoleptic properties (Emer et al., 2008).

Both ECAW and ozone are effective sanitizers for inactivating foodborne pathogens (Abadias, Usall, Oliveira, Alegre, & Vinas, 2008; Ayebah, Hung, & Frank, 2005; Ayebah, Hung, Kim, & Frank, 2006; Deza et al., 2003, 2005, 2007; Emer et al., 2008; Guentzel et al., 2008; Hricova et al., 2008; Pascual et al., 2007; Vurma et al., 2009), but the equipment for generating ECAW or ozonation is typically quite large and expensive for applications at households and small business. In addition, the relative short shelf life of the sanitizing solutions generated may also limit their application in small scale. These limitations, have led to demand for small sized and affordable ECAW or ozone generator. To meet this market need, currently, several companies have developed portable water sanitizing equipment advertising effective sanitization. According to informational materials, these types of equipment also use some sort of electrolysis processing for generating sanitizing waters. However, to the best our knowledge, there are no independent studies supporting their sanitizing claims.

This study was undertaken to investigate the sanitizing effects of some of these commercial technologies and provide guidance for consumers when considering sanitizing equipment. The objectives of this study were to evaluate the efficacy of water products made from several commercial technologies on *E. coli* O157:H7, *Salmonella* and *L. monocytogenes* inactivation.

2. Materials and methods

2.1. Bacterial strains

Strains of *E. coli* O157:H7 (ATCC 43890, ATCC 43895, 2028, 2257, 2029), *Salmonella enterica* (Typhimurium ATCC 14028, Typhimurium E2009005811, Enteritidis 2009595, Tennessee E2007000302, and Saintpaul E2008001236) and *L. monocytogenes* (ATCC 19115, DUP-1030A, DUP-1038, DUP-1044A, and 2422) were included. For each strain, a loop of −60 °C storage culture was inoculated, transferred for three consecutive times in tryptic soy broth (TSB) (Neogen, Inc., Lansing, MI, USA) and inoculated at 37 °C at 24 h intervals.

2.2. Preparation and assessment of water sanitizers

ECAW was generated from a generator STEL 80 ECT US (Zap Water Technology, Inc, Richfield, MN, USA) using tap water and saturated NaCl solutions at a voltage of 7–9 V. After the machine reached a stable voltage reading, ECAW was collected from the anode side into a sterile glass beaker, covered to prevent the loss of chlorine and used within 2 h post-production. Free available chlorine (FAC), pH, and oxidation-reduction potential (ORP) of ECAW were determined by a chorine test kit using a drop count method (LaMotte Company, Chestertown, MD, USA), a pH meter (Oakton Instruments Inc., Vernon Hills, IL, USA) and an ORP meter (Oakton Instruments Inc.), respectively. The ECAW generated was diluted to 50 mg/L (E50) (ORP 824 ± 5 mV, pH 7.0 ± 0.1) and 100 mg/L (E100) (ORP 864 ± 7 mV, pH 7.0 ± 0.1) FAC for liquid culture test and surface testing, respectively.

For other commercial technologies including control group, sterile tap water was used and prepared using 0.22 μM filters (Falcon, Oxnard, CA, USA) (No detection of FAC, ORP 354 ± 6 mV, pH 7.1 ± 0.1). Ionator™ EXP was purchased from Active ion Cleaning Solutions, LLC (Rogers, MN, USA). Ionator EXP was operated using tap water and tap water with 0.1% NaCl. Lotus™ sanitizing system (Model LSR 100, Tersano SRL, Buffalo, NY) also used with filter-sterilized tap water. Sterile tap water and salt-containing tap water were loaded onto the Ionator™ EXP sprayer, produced and delivered (designated as I and S, respectively) by turning the spraying device on. No chlorine was detected for both I and S waters, while ORP and pH values were 358 ± 5 mV and 7.0 ± 0.1 for I and 359 ± 6 mV and 7.0 ± 0.1 for S. The filtered tap water for Lotus™ was cooled to 4 °C before transferred to the machine according to the manufacturer's instructions. Then the equipment was turned on and the water within the container circulated until the apparatus indicated that the cycle was complete (designated as L). Ozone concentration of Lotus™ solution was 0.25 ± 0.12 mg/L, determined by SenSafe™ Ozone Check (Industrial Test Systems Inc., Rock Hill, SC, USA).

2.3. Liquid culture testing

For each bacterial group, 30 mL cultures of 24 h were centrifuged for 10 min (3600 × *g*, 4 °C). Pellets were washed using 15 mL peptone water (PW), centrifuged and re-suspended in 15 mL PW. For all the water sanitizers except Ionator™, 1 mL resuspended bacterial suspensions were added into bottles containing 99 mL of solution generated by different commercial technologies (or filtered tap water as control). For Ionator™ streams, 20 mL of generated solution were pre-added to bottles, 1 mL culture were added and additional 79 mL of the solutions were sprayed according to the manufacturer's instructions. Bottles were shaken by hand for 30 s. Volumes of 1 mL of bacteria-solution mixtures were transferred to 9 mL neutralizing buffer solutions and shaken for

40 s (5.2 g/L; Becton Dickinson, Sparks, MD, USA). The neutralized mixture was then serially diluted. Two 0.1 mL aliquots of the diluents were plated on tryptic soy agar (TSA; Neogen, Inc., Lansing, MI, USA) plates which were incubated at 37 °C for 24 h for *E. coli* O157:H7 and *Salmonella* or 48 h for *L. monocytogenes*. Recovered bacteria were enumerated by counting the colony forming unit (CFU) (Ayebah et al., 2006). Bacterial counts as CFU were calculated per mL and the data were transformed to logarithm base 10.

2.4. Bacteria dried on stainless steel surface

For each strain, approximately 10 mL of 24-h cultures were centrifuged as above. Pellets were washed with 5 mL sterile TSB, centrifuged and re-suspended in 2 mL TSB. Volumes of 25 μL of bacterial suspensions were inoculated on clean sterile stainless steel coupons in Petri dish. The Petri dishes and coupons were dried in a biosafety cabinet for 3 h. Different solutions from each of the control and treatments were sprayed on inoculated coupons for 6 s at a distance of 7–10 cm. The coupon surface was wiped dry with a clean sterile cloth (around 3 cm × 3 cm). The coupon and the cloth, respectively, were placed in clean Petri dishes containing 10 mL neutralizing buffer for 40 s, transferred to 50 mL sterile plastic tubes, added with 10 mL PW and 15–20 glass beads (3 mm) using sterile forceps, and vortexed with full velocity for 2 min. Sprayed solutions were kept in the Petri dishes for an additional 54 s, then 0.1 mL of the sprayed solutions were plated on TSA plates (Yang, Kendall, Medeiros, & Sofos, 2009). Bacterial counts as CFU were calculated per stainless steel coupon and the data were transformed to logarithm base 10.

2.5. Data analysis

For each strain, at least two separate trials were independently conducted. For each trial, parallel groups were conducted in duplicate with two serials of plating results for any individual condition. Statistical analyses using analysis of variance (ANOVA) ($P < 0.05$) and Tucky Test for differences among different treatments were performed using SAS software (Version 9.1.3, SAS, Cary, NC, USA). Comparisons that yield $P < 0.05$ were considered significant.

3. Results

The detection limits for the recovery of *E. coli* O157:H7, *Salmonella* and *L. monocytogenes* from liquid culture and on stainless steel coupon surface were 2 log CFU/mL and 2 log CFU/coupon, respectively, due to the neutralization step and 0.1 mL of the maximum plating volume of coupon/buffer mixture or liquid culture/buffer mixture. All the results were presented with the assumption that the survival of foodborne pathogens at levels below the detection limits could not be quantified. Thus, when no colony was found on the plates, the result was assigned a value of 2 log CFU/mL or 2 log CFU/coupon level.

Table 1 shows the effect of different water fractions on the recovery of 5 individual *E. coli* O157:H7 strains in liquid culture. None of the treatments with I, S or L water fractions reduced the cell count of liquid cultures compared with controls. Treatment of ECAW (50 mg/L FAC) of liquid bacterial cultures caused at least 5 log CFU/mL viable cell count reductions ($P < 0.05$) in all strains with the exception of strain ATCC 43895 which was only killed by 2 log CFU/mL. When ECAW fractions with concentrations of 100 mg/L FAC were tested, no survivors were detected.

Similar results were obtained with *Salmonella* strains in liquid cultures (Table 2) as only ECAW treatments yield significant viable count reductions. Exposure to ECAW (50 mg/L FAC) resulted in more than 3 log CFU/mL reductions for all *Salmonella* strains and no detectable levels were found with 100 mg/L FAC. Liquid cultures of *L. monocytogenes* were also only susceptible to ECEW among all water treatments (Table 3). Both levels of FAC caused more than 5 log CFU/mL decreases in cell viability to all the strains tested for this Gram positive organism.

E. coli O157:H7, *Salmonella* and *L. monocytogenes* cells dried on stainless steel coupon surface exposed to the different water treatments were determined in each of the following fractions: coupons, wiping cloths, and the rinsing solution after treatment (Tables 4–6). For control, L, I, and S treatments, from an initial inoculation of approximately 7 log CFU/coupon, more than 90% of the count was consistently recovery in the water treatment originally sprayed on the coupon (rinse). In all of those treatments, the count of *E. coli* O157:H7 strains remaining on coupons ranged from 2.2 to 3.0 log CFU and transferred to wiping cloth from 3.4 to 4.1 log CFU (Table 4). The recovery of *Salmonella serovars* on coupons was slightly higher than for *E. coli* O157:H7 and for *L. monocytogenes*, but it never reached more than 4.0 log CFU. When any of the pathogenic bacteria strains were sprayed with ECAW (100 mg/L FAC) no survivors were detected above the detection level in any coupon, cloth and rinse.

4. Discussion

Sanitization plays a very important role in improving food safety. Recently, a few technologies that offer some electrical treatment of plain water have been marketed to the food service industry as a convenient and chemical-free alternative. In this study, two of those commercially available sanitizing water technologies were tested and compared with ECAW. In one of them, the

Table 1
Effect of water fractions previously treated with different electrolysis technology on the viability of *Escherichia coli* O157:H7 liquid cultures[a].

Strain	Survival count after treatment (log CFU/mL)					
	Control	I[b]	S[c]	L[d]	E50[e]	E100[f]
ATCC 43890	7.04 ± 0.03 A	7.02 ± 0.04 A	7.05 ± 0.06 A	7.03 ± 0.09 A	2.07 ± 0.30 B	<2.00[g] C
ATCC 43895	7.16 ± 0.02 A	7.15 ± 0.07 A	7.14 ± 0.06 A	7.14 ± 0.16 A	4.90 ± 0.65 B	<2.00 C
2028	7.17 ± 0.05 A	7.14 ± 0.05 A	7.12 ± 0.03 A	7.09 ± 0.08 A	<2.00 B	<2.00 B
2257	7.19 ± 0.04 A	7.17 ± 0.03 A	7.17 ± 0.05 A	7.08 ± 0.09 A	<2.00 B	<2.00 B
2029	7.10 ± 0.04 A	7.10 ± 0.05 A	7.07 ± 0.07 A	7.04 ± 0.08 A	<2.00 B	<2.00 B

[a] Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 50 mg/L.
[f] NECAW with FAC 100 mg/L.
[g] Detection limit: 2.00 log CFU/mL.

Table 2
Effect of water fractions previously treated with different electrolysis technology on the viability of *Salmonella* spp. liquid cultures[a].

Serovar and strain	Survival count after treatment (log CFU/mL)					
	Control	I[b]	S[c]	L[d]	E50[e]	E100[f]
Typhimurium ATCC 14028	7.10 ± 0.04 A	7.05 ± 0.04 A	7.12 ± 0.05 A	7.03 ± 0.06 A	3.47 ± 0.26 B	<2.00[g] C
Typhimurium E2009005811	7.04 ± 0.07 A	7.00 ± 0.08 A	7.03 ± 0.06 A	7.02 ± 0.06 A	<2.00 B	<2.00 B
Enteritidis 2009595	7.26 ± 0.04 A	7.24 ± 0.10 A	7.25 ± 0.09 A	7.23 ± 0.05 A	<2.00 B	<2.00 B
Tennessee E2007000302	7.34 ± 0.05 A	7.30 ± 0.08 A	7.33 ± 0.07 A	7.26 ± 0.16 A	3.05 ± 0.40 B	<2.00 C
Saintpaul E2008001236	7.10 ± 0.06 A	7.08 ± 0.07 A	7.07 ± 0.06 A	7.05 ± 0.12 A	3.69 ± 0.60 B	<2.00 C

[a] Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 50 mg/L.
[f] NECAW with FAC 100 mg/L.
[g] Detection limit: 2.00 log CFU/mL.

water was supplemented with salt to determine if it would increase antimicrobial activity. The results indicated that with the exception of ECAW, all water sanitizers tested were not effective in inactivating *E. coli* O157:H7, *Salmonella* and *L. monocytogenes*, three representative foodborne pathogens, either in liquid culture or dried on surface.

Ozonized water has been determined to have almost no effect on food quality properties (Hassenberg et al., 2007). However, efficiency of ozone is affected by 'ozone demand of the medium's residual ozone, which means the ozone remained on food product or equipment after its application, is also needed (Karaca & Velioglu, 2007). Ozonated water was reported to be effective in the literature; however, the water contained enough ozone content (Guentzel et al., 2008; Trindade, Kushida, Villanueva, Pereira, & de Oliveira, 2012). These effective ozonated water had higher ozone concentration than solution L that we used (0.25 mg/L) in the current manuscript. One possible reason why L was not effective may be that the equipment used relatively low-power treatments, i.e., the current and voltage were not high enough, so not enough ozone was generated to exert sufficient sanitizing effects (Fishburn, Tang, & Frank, 2012). Ozone is a versatile antimicrobial agent that is relatively stable in air but highly unstable in water, decomposing in a very short time. Due to this property, another possible reason why L did not work could be that the ozone generated by equipment L is in a much more unstable form than that generated by large-scale machines. Considering the L water was applied immediately after its preparation, the chance of the second reason was highly unlikely. To test any of these hypotheses, further work measuring the ozone concentration after treatment would need to be conducted.

The user manual of I indicated that tap water without chlorine-containing salt is enough for generating sanitizers that have sanitizing effects of at least 3 log reductions (http://www.activeion.com/EXP.aspx#frame4). The manufacturer even provided a cartoon showing the electrolysis process with ion exchange and electrically charged nanobubbles. However, our results indicate that its effectiveness did not match the manufacturer's claims. The lack of effect of this technology could be due to the lack of an active chemical component as tap water was the only component. In the case of ECAW, if sodium chloride is not present before electrolysis, the resulting fraction is largely non-effective (data not shown). Tap water itself cannot be electrolyzed to generate high ORP either because limited current and voltage can be applied for electrolysis due to the absence of electrolyte. The commercial technologies tested here were clearly not effective sanitizers, supporting the importance of electrolytes during electrolysis.

For better understanding the electrolysis and the reasons why the two waters did not work, 0.1% NaCl solution was applied to I (S). Even this S can not be generated into effective sanitizing components. Although the effectiveness of electrolyzed water has been widely documented in the literature (Abadias et al., 2008; Ayebah et al., 2005; Ayebah et al., 2006; Deza et al., 2003, 2005, 2007; Guentzel et al., 2008; Issa-Zacharia, Kamitani, Morita, & Iwasaki, 2010; Kim et al., 2003; Kiura et al., 2002; Koseki & Itoh, 2000; Liao, Chen, & Xiao, 2007; Liu, Duan, & Su, 2006; Liu & Su, 2006; Oomori, Oka, Inuta, & Arata, 2000; Yang, Swem, & Li, 2003), these waters were generated by relatively large equipment with high power, and had been electrolyzed sufficiently, thus can have sufficient sanitizing effects. One possible reason could be that the electrical power delivered by I was not sufficient to cause electrolysis. The results of no sanitizing effects by 0.1% NaCl indicated that this portable equipment used to generate sanitizing components might not be sufficiently powerful (Tables 1–6).

Previous results about the antimicrobial activity of ECAW on foodborne pathogens varied significantly (Hricova et al., 2008;

Table 3
Effect of water fractions previously treated with different electrolysis technology on the viability of *Listeria monocytogenes* liquid cultures[a].

Strain	Survival count after treatment (log CFU/mL)					
	Control	I[b]	S[c]	L[d]	E50[e]	E100[f]
ATCC 19115	7.24 ± 0.03 A	7.17 ± 0.09 A	7.19 ± 0.04 A	7.21 ± 0.04 A	<2.00[g] B	<2.00 B
DUP-1030A	7.23 ± 0.03 A	7.19 ± 0.04 A	7.19 ± 0.01 A	7.20 ± 0.03 A	<2.00 B	<2.00 B
DUP-1038	7.53 ± 0.05 A	7.50 ± 0.04 A	7.51 ± 0.04 A	7.51 ± 0.04 A	<2.00 B	<2.00 B
DUP-1044A	7.08 ± 0.07 A	7.10 ± 0.07 A	7.10 ± 0.04 A	7.04 ± 0.05 A	<2.00 B	<2.00 B
2422	6.58 ± 0.05 A	6.54 ± 0.12 A	6.61 ± 0.05 A	6.52 ± 0.11 A	<2.00 B	<2.00 B

[a] Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 50 mg/L.
[f] NECAW with FAC 100 mg/L.
[g] Detection limit: 2.00 log CFU/mL.

Table 4
Survival of *Escherichia coli* O157:H7 dried on coupons after treatment with antimicrobial water treatments (log CFU/coupon)[a].

Strain	Testing fraction	Survival count after treatment				
		Control	I[b]	S[c]	L[d]	E100[e]
ATCC 43890	Coupon	2.38 ± 0.20 A	2.31 ± 0.12 A	2.42 ± 0.13 A	2.35 ± 0.56 A	<2.00[f] B
	Cloth	3.50 ± 0.06 A	3.48 ± 0.11 A	3.48 ± 0.09 A	3.46 ± 0.11 A	<2.00 B
	Rinse	6.60 ± 0.18 A	6.64 ± 0.10 A	6.65 ± 0.12 A	6.63 ± 0.12 A	<2.00 B
ATCC 43895	Coupon	3.01 ± 0.21 A	2.93 ± 0.09 A	3.00 ± 0.12 A	2.94 ± 0.08 A	<2.00 B
	Cloth	3.44 ± 0.11 A	3.44 ± 0.01 A	3.40 ± 0.02 A	3.39 ± 0.04 A	<2.00 B
	Rinse	6.70 ± 0.15 A	6.71 ± 0.14 A	6.70 ± 0.14 A	6.72 ± 0.12 A	<2.00 B
2028	Coupon	2.98 ± 0.19 A	2.68 ± 0.23 A	2.80 ± 0.33 A	2.61 ± 0.17 A	<2.00 B
	Cloth	4.10 ± 0.04 A	4.06 ± 0.05 A	4.07 ± 0.10 A	3.99 ± 0.05 A	<2.00 B
	Rinse	6.54 ± 0.16 A	6.52 ± 0.21 A	6.51 ± 0.20 A	6.50 ± 0.21 A	<2.00 B
2257	Coupon	2.72 ± 0.67 A	2.16 ± 0.38 A	2.28 ± 0.28 A	2.23 ± 0.29 A	<2.00 B
	Cloth	3.85 ± 0.37 A	3.78 ± 0.34 A	3.83 ± 0.28 A	3.73 ± 0.38 A	<2.00 B
	Rinse	6.45 ± 0.04 A	6.50 ± 0.08 A	6.51 ± 0.05 A	6.47 ± 0.08 A	<2.00 B
2029	Coupon	2.57 ± 0.66 A	2.24 ± 0.26 A	2.30 ± 0.20 A	2.11 ± 0.29 A	<2.00 B
	Cloth	3.47 ± 0.09 A	3.45 ± 0.07 A	3.43 ± 0.10 A	3.38 ± 0.13 A	<2.00 B
	Rinse	6.37 ± 0.42 A	6.47 ± 0.37 A	6.44 ± 0.36 A	6.47 ± 0.38 A	<2.00 B

[a] Initial number of microbial cells was 6.94 ± 0.03, 7.02 ± 0.18, 7.10 ± 0.15, 6.50 ± 0.08, 6.96 ± 0.33 for strains 43890, 43895, 2028, 2257, and 2029, respectively. Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 100 mg/L.
[f] Detection limit: 2.00 log CFU/coupon.

Huang et al., 2008; Park et al., 2004). Many researchers have demonstrated that ECAW can generate 2 to 6 log CFU reductions of some bacteria such as *E. coli* O157:H7, *Salmonella*, and *L. monocytogenes* (Deza et al., 2003; Issa-Zacharia et al., 2010). Our results showed ECAW resulted in 3 to more than 5 log CFU reductions for *E. coli* O157:H7, *L. monocytogenes*, and *Salmonella* in liquid culture, which was comparable to published results.

In general, ECAW for bacteria dried on surfaces is less effective and more variable than it is for liquid suspensions. For *L. monocytogenes* dried on surfaces, acidic ECAW (40 mg/L, pH 2.65, ORP 1155) only resulted in 1.91 log CFU reductions per chip dirty stainless steel, having 0.88 more reductions than tap water (Liu et al., 2006). In the present report, only ECAW fractions containing 100 mg/L FAC were applied for surface treatment. The survival of microbial cells from all the five fractions collected were below detection limits by 100 mg/L FAC, indicating that ECAW at this concentration can effectively stop cross contamination during food processing. Several factors may affect the antimicrobial effects of ECAW on surfaces and increase variability (Liu et al., 2006; Liu & Su, 2006). Organochloramine and organochlorine are formed when chlorine compounds react with organic compounds on surfaces (Ayebah et al., 2005; Oomori et al., 2000; Park, Alexander, Taylor, Costa, & Kang, 2008), resulting in reduced ability to penetrate into the protective layer of microbial polymers and reduced sanitizing effects (Al-Haq, Sugiyama, & Isobe, 2005; Park, Hung, & Kim, 2002). This may explain why ECAW is less effective in surface than in liquid culture and why with similar parameters sanitizing effects of ECAW on foods and surfaces varied more greatly as compared with liquid culture bacteria (Guentzel et al., 2008; Yang et al., 2003).

In conclusion, this study investigated the sanitizing effects of two commercial technologies, which are commercially available and are recommended by their manufacturers to consumers, on

Table 5
Survival of *Salmonella* spp. dried on coupons after treatment with antimicrobial water treatments (log CFU/coupon)[a].

Strain	Testing fraction	Survival count after treatment				
		Control	I[b]	S[c]	L[d]	E100[e]
Typhimurium ATCC 14028	Coupon	3.29 ± 0.26 A	3.23 ± 0.29 A	3.26 ± 0.24 A	3.19 ± 0.20 A	<2.00[f] B
	Cloth	3.54 ± 0.30 A	3.47 ± 0.32 A	3.46 ± 0.32 A	3.46 ± 0.36 A	<2.00 B
	Rinse	6.95 ± 0.26 A	6.98 ± 0.23 A	6.99 ± 0.22 A	6.93 ± 0.25 A	<2.00 B
Typhimurium E2009005811	Coupon	3.77 ± 0.08 A	3.73 ± 0.09 A	3.74 ± 0.09 A	3.67 ± 0.17 A	<2.00 B
	Cloth	3.96 ± 0.03 A	3.93 ± 0.02 A	3.92 ± 0.03 A	3.78 ± 0.20 A	<2.00 B
	Rinse	6.92 ± 0.30 A	6.95 ± 0.28 A	6.95 ± 0.29 A	6.89 ± 0.30 A	<2.00 B
Enteritidis 2009595	Coupon	3.62 ± 0.42 A	3.49 ± 0.16 A	3.51 ± 0.17 A	3.47 ± 0.54 A	<2.00 B
	Cloth	3.81 ± 0.25 A	3.70 ± 0.14 A	3.71 ± 0.15 A	3.55 ± 0.40 A	<2.00 B
	Rinse	6.88 ± 0.25 A	6.81 ± 0.23 A	6.79 ± 0.25 A	6.83 ± 0.18 A	<2.00 B
Tennessee E2007000302	Coupon	3.30 ± 0.16 A	3.19 ± 0.24 A	3.31 ± 0.21 A	3.16 ± 0.30 A	<2.00 B
	Cloth	3.99 ± 0.14 A	3.95 ± 0.16 A	3.99 ± 0.17 A	3.88 ± 0.20 A	<2.00 B
	Rinse	7.14 ± 0.22 A	7.16 ± 0.20 A	7.16 ± 0.22 A	7.09 ± 0.27 A	<2.00 B
Saintpaul E2008001236	Coupon	3.87 ± 0.23 A	3.72 ± 0.14 A	3.77 ± 0.25 A	3.75 ± 0.32 A	<2.00 B
	Cloth	3.29 ± 0.26 A	3.23 ± 0.29 A	3.26 ± 0.24 A	3.19 ± 0.20 A	<2.00 B
	Rinse	7.11 ± 0.18 A	7.10 ± 0.20 A	7.09 ± 0.21 A	7.03 ± 0.27 A	<2.00 B

[a] Initial number of microbial cells was 7.22 ± 0.20, 7.36 ± 0.29, 7.31 ± 0.24, 7.97 ± 0.21, 7.71 ± 0.43 for Typhimurium ATCC 14028, Typhimurium E2009005811, Enteritidis 2009595, Tennessee E2007000302, and Saintpaul E2008001236, respectively. Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 100 mg/L.
[f] Detection limit: 2.00 log CFU/coupon.

Table 6
Survival of *Listeria monocytogenes* dried on coupons after treatment with antimicrobial water treatments (log CFU/coupon)[a].

Strain	Testing fraction	Survival count after treatment				
		Control	I[b]	S[c]	L[d]	E100[e]
ATCC 19115	Coupon	3.28 ± 0.2 A	3.15 ± 0.3 A	3.14 ± 0.2 A	3.20 ± 0.2 A	<2.00[f] B
	Cloth	3.19 ± 0.2 A	3.12 ± 0.2 A	3.17 ± 0.2 A	3.20 ± 0.3 A	<2.00 B
	Rinse	6.2 ± 0.1 A	5.89 ± 0.6 A	5.91 ± 0.6 A	5.91 ± 0.6 A	<2.00 B
DUP- 1030A	Coupon	3.26 ± 0.3 A	3.2 ± 0.25 A	3.13 ± 0.3 A	3.32 ± 0.3 A	<2.00 B
	Cloth	3.35 ± 0.2 A	3.1 ± 0.26 A	3.2 ± 0.28 A	3.44 ± 0.2 A	<2.00 B
	Rinse	6.73 ± 0.5 A	6.58 ± 0.6 A	6.57 ± 0.6 A	6.64 ± 0.6 A	<2.00 B
DUP- 1038	Coupon	3.3 ± 0.36 A	3.1 ± 0.28 A	3.19 ± 0.4 A	3.1 ± 0.24 A	<2.00 B
	Cloth	3.4 ± 0.34 A	3.13 ± 0.2 A	3.22 ± 0.2 A	3.2 ± 0.18 A	<2.00 B
	Rinse	6.8 ± 0.95 A	6.4 ± 0.74 A	6.38 ± 0.7 A	6.45 ± 0.8 A	<2.00 B
DUP- 1044A	Coupon	3.30 ± 0.3 A	3.06 ± 0.2 A	3.2 ± 0.25 A	3.0 ± 0.37 A	<2.00 B
	Cloth	3.44 ± 0.3 A	3.13 ± 0.2 A	3.2 ± 0.15 A	3.11 ± 0.2 A	<2.00 B
	Rinse	6.61 ± 0.6 A	6.24 ± 0.4 A	6.25 ± 0.5 A	6.31 ± 0.4 A	<2.00 B
2422	Coupon	3.19 ± 0.2 A	3.1 ± 0.18 A	3.12 ± 0.2 A	3.24 ± 0.1 A	<2.00 B
	Cloth	3.3 ± 0.26 A	3.2 ± 0.24 A	3.06 ± 0.2 A	3.3 ± 0.25 A	<2.00 B
	Rinse	6.4 ± 0.46 A	6.0 ± 0.65 A	6.03 ± 0.6 A	6.35 ± 0.4 A	<2.00 B

[a] Initial number of microbial cells was 6.80 ± 0.11, 7.15 ± 0.52, 7.31 ± 0.50, 7.29 ± 0.42, 6.78 ± 0.19 for ATCC 19115, DUP-1030A, DUP-1038, DUP-1044A, and 2422, respectively. Within each row, means with different capital letters are significantly different ($P < 0.05$).
[b] Made from commercial product and technology I (Ionator™).
[c] Made from commercial product and technology S (Ionator using 0.1% NaCl solution).
[d] Made from commercial product and technology L (Lotus™).
[e] Neutral electrochemically activated water (NECAW) with free available chlorine (FAC) 100 mg/L.
[f] Detection limit: 2.00 log CFU/coupon.

E. coli O157:H7, *Salmonella* and *L. monocytogenes* in liquid or dried on stainless steel surface. All the water sanitizers tested were not effective in sanitizing any of the above foodborne pathogens except ECAW. The reasons why they did not have sanitizing effects were explained. The result is helpful for guiding food service operators and consumers to choose effective sanitizers for ensuring food safety.

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