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Efficacy of Neutral Electrolyzed Water To Inactivate *Escherichia coli, Listeria monocytogenes, Pseudomonas aeruginosa,* and *Staphylococcus aureus* on Plastic and Wooden Kitchen Cutting Boards

M. A. DEZA,* M. ARAUJO, AND M. J. GARRIDO

Institute of Food Research and Analysis, University of Santiago de Compostela, E-15782 Santiago de Compostela, Spain

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ABSTRACT

This study evaluated the efficacy of neutral electrolyzed water (NEW; 64.1 mg/liter of active chlorine) to reduce populations of *Escherichia coli, Pseudomonas aeruginosa, Staphylococcus aureus,* and *Listeria monocytogenes* on plastic and wooden kitchen cutting boards. Its effectiveness was compared with that of a sodium hypochlorite solution (NaClO; 62.3 mg/liter of active chlorine). Inoculated portions of cutting boards were rinsed in either NEW or NaClO solutions, or deionized water (control). Plastic boards were rinsed for 1 min and wooden boards for 1 and 5 min. After each treatment, the surviving population of each strain was determined on the surface and in the soaking water. No significant difference ($P \geq 0.05$) was found between the final populations of each strain with regard to the treatment solutions (NEW or NaClO). However, a significant difference ($P \leq 0.05$) was revealed between surface materials after 1 min of washing. Whereas in plastic boards the initial bacterial populations were reduced by 5 log CFU/50 cm^2, in wooden cutting boards they underwent a reduction of <3 log CFU/50 cm^2. A 5-min exposure time yielded reductions of about 4 log CFU/50 cm^2. The surviving populations of all bacteria in NEW and NaClO washing solutions were <1 log CFU/ml after soaking both surfaces. This study revealed that NEW treatment is an effective method for reducing microbial contamination on plastic and wooden cutting boards. NEW efficacy was comparable to that of NaClO, with the advantage of having a larger storage time.

Food contact surfaces have been repeatedly pointed at as vehicles of bacterial cross-contamination: residues of fluid from raw meat or poultry remaining on a cutting surface might transfer disease agents to other foods that would not be cooked further before eating. In this respect, a source of special concern is the use of cutting boards for food preparation in both household and food service kitchens. It has been shown that when chopping boards become contaminated, pathogens can survive and even multiply on the surface, and are readily transferred to other surfaces in numbers sufficient to represent an infection hazard *(13, 33, 34).* Foodborne pathogens like *Salmonella* spp., *Campylobacter* spp., *Bacillus cereus, Staphylococcus aureus,* and *Listeria monocytogenes* have been isolated from food contact surfaces and utensils in domestic kitchens *(8).*

Contrary to popular perception, epidemiological data indicate that most foodborne disease outbreaks arise from infection within the home *(28)*; moreover, poor hygiene involving the hands and other surfaces is cited as a contributory factor in up to 39% of domestic food poisoning outbreaks *(25).* Several surveys have shown that one in five consumers does not routinely wash hands or chopping boards after cutting raw meat or chicken *(3, 18).*

The U.S. Food and Drug Administration advises consumers to use smooth, durable, nonabsorbent cutting boards made of substances such as plastic or hard maple *(30).* Various authors have found wooden cutting boards to be more difficult to clean than plastic boards because the physical structure of wood can absorb moisture and retain bacteria *(9, 34),* so the difficulty in removing these bacteria may make this material less desirable from a food safety perspective. In contrast, other studies *(1, 2, 26)* have shown that inoculated bacteria are harder to recover from wooden boards than from plastic ones; they also indicate that some woods may contain endogenous antibacterial properties, and that the hygroscopic characteristics of the material may lead to desiccation of bacteria. Nonetheless, because porous or scarred cutting boards (be they plastic or wooden) are harder to clean than new boards *(2),* there is a need to control the sanitation of food contact surfaces, regardless of their composition, to prevent cross-contamination.

Frequent cleaning and disinfection of food-preparation surfaces is an effective means to reduce cross-contamination and the occurrence of foodborne disease outbreaks. However, rinsing with water and domestic chemical cleaners does not ensure total elimination of bacteria from cutting boards *(12, 33)*; hence, antimicrobial agents become necessary to achieve complete hygiene of the surfaces. The spectrum of disinfectants used in kitchens and food industries is wide: it includes quaternary ammonium compounds, amphoteric products, biguanides, iodophors, and peroxo acids *(26, 27).* The use of chlorine-containing compounds is one of the most common disinfection methods because

* Author for correspondence: Tel: +34 981 563 100 (ext. 16025); Fax: +34 981 547 171; E-mail: madeza@usc.es.

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these compounds are effective against bacteria and require short to moderate contact time *(16).* Sodium hypochlorite (NaClO) is one of the most widely used disinfectants in household sites, but it has the disadvantage of being unstable because the active chlorine concentration in the solution deteriorates with time, exposure to light, and elevated temperature and on contact with air *(11, 29).* In addition, the handling of concentrated NaClO is a potential hazard for food handlers.

In recent years, acidic electrolyzed water (AEW) and neutral electrolyzed water (NEW) have been introduced for application as sanitizers. These solutions are generated by electrolysis of a dilute NaCl solution passing through the anode of a membrane electrolyzer. AEW has a low pH (2 to 4), high oxidation-reduction potential (ORP $>$ 1000 mV), a strong bactericidal effect on most known pathogenic bacteria *(16, 31),* and is effective for the disinfection of different food-processing surfaces *(23, 32)* and inactivation of biofilms *(7, 17).* NEW is produced in a similar way than AEW, but it is partially mixed with OH^- that is transferred through the membrane into the cathode chamber. This produces a neutral solution (pH 8 $\pm$ 0.5 [SD]; ORP 750 $\pm$ 50 mV and 450 $\pm$ 50 mg/liter of active chlorine) in which the main biocidal reagents are HOCl, ClO^-, HO_2, and $^{\bullet}O_2$. Because of its neutral pH, NEW is less aggressive than AEW regarding the corrosion of processing equipment and the irritation of hands *(6).* Moreover, NEW has a longer storage life than AEW because chlorine loss is greatly reduced *(19, 22).* Taking these facts into account, NEW is advantageous over AEW for the disinfection of food contact surfaces.

NEW has proved to be effective in removing biofilms in dental unit water lines *(21)* and more effective than NaClO as an irrigating solution for endodontic treatment *(20).* Previous studies in our laboratory have demonstrated that rinsing in NEW is an effective way to control the presence of pathogenic bacteria on the surface of fresh tomatoes *(14)* and reduces the presence of pathogenic and spoilage bacteria on stainless steel and glass surfaces *(15).*

The aim of this work was to evaluate the efficacy of NEW in reducing populations of *Escherichia coli, Pseudomonas aeruginosa, S. aureus,* and *L. monocytogenes* on plastic and wooden cutting boards. Its effectiveness for that purpose was compared with that of a NaClO solution with similar pH, ORP, and active chlorine content. The shelf life of NEW and NaClO solutions in different storage conditions was also evaluated.

MATERIALS AND METHODS

Bacterial cultures. The strains used for this study were obtained from the Spanish Type Culture Collection (CECT): *Escherichia coli* CECT 405 (American Type Culture Collection [ATCC] strain 10536, proposed for testing antibiotics, antimicrobial preservatives, and chemotherapeutic agents), *Pseudomonas aeruginosa* CECT 116 (ATCC 15442, proposed for testing slimicides and disinfectants), *Staphylococcus aureus* CECT 239 (ATCC 6538, proposed for testing surface sanitizers and antimicrobial agents), and *Listeria monocytogenes* CECT 4032 (isolated from soft cheese, associated with a case of meningitis). Strains were cultured on tryptone soy broth (TSA; Panreac Química S.A., Barcelona, Spain) plates with the addition of 15 g/liter agar no. 3 (Oxoid, Basingstoke, Hampshire, UK) at 37°C for 24 h. For the inoculation of surfaces, bacteria were harvested from the TSA plates with a sterile glass bent rod and resuspended in 50 ml of tryptone–sodium chloride solution (pH 7.2 $\pm$ 0.2), to obtain a suspension of 9 to 10 log CFU/ml. The bacterial population of each inoculum was confirmed by pouring 1 ml of appropriate dilutions of the suspension (using the same solution) on duplicate TSA plates, and incubating at 37°C for 24 h.

Preparation of treatment solutions. NEW was generated with an Envirolyte El-900 unit (Envirolyte Industries Internacional Ltd., Tallin, Estonia). A 25% sodium chloride solution and tap water were simultaneously pumped into the generator to obtain amperage of 32 $\pm$ 2 A. For the evaluation of storage life, NEW (containing approximately 400 mg/liter of active chlorine) was used pure. For the treatment of cutting boards, NEW was diluted in deionized sterile water to obtain a final active chlorine concentration of about 60 mg/liter. NaClO solution was prepared by mixing NaClO (Panreac Química) and deionized water to obtain a final active chlorine concentration of about 340 mg/liter for the shelf-life study, or approximately 60 mg/liter for the washing of cutting boards. Deionized sterile water was used as control. Properties of the treatment solutions were measured immediately after preparation. pH and ORP were measured with a pH-ion-conductivity meter (CRISON micro-pH 2001; Crison Instruments, Barcelona, Spain) with a pH electrode (CRISON 52-11) and an ORP electrode (CRISON platinum Ag/AgCl electrode, 52–61). Active chlorine concentration was measured by an iodometric method *(4).* NEW and NaClO solutions were used within 4 h of preparation.

Storage life of NEW and NaClO solutions. NEW and NaClO solutions were prepared as described in ''Preparation of treatment solutions.'' A total of 1,000 ml of each solution was poured into transparent glass bottles and stored for 54 days in open or closed conditions at either 4°C under artificial light, or at room temperature at 23 $\pm$ 2°C in the presence of natural light. For closed storage, the bottle was sealed with a screw cap. The pH, ORP, and active chlorine concentration of NEW and NaClO solutions were periodically measured during storage.

Bactericidal activity of stored solutions. The efficiency of NEW and NaClO stored solutions to produce a reduction of at least 5 log CFU/ml in viable cell counts (bactericidal activity) in clean conditions was evaluated according to European Standard UNE-EN 1276 *(5).* Nine milliliters of either NEW or NaClO solution was added to sterile tubes containing 1 ml of *Escherichia coli* CECT 405 culture of approximately 8.5 log CFU/ml prepared as described in ''Bacterial cultures.'' The tubes were hand-shaken to mix the resultant suspension and incubated at room temperature (23 $\pm$ 2°C) for 5 min. Deionized water was used as control. After treatment, 1 ml of each sample was transferred to 9 ml of neutralizing solution (sodium thiosulfate 0.5%), and the suspension was hand-shaken. After 5 min of neutralization, 1 ml of the appropriate dilution in tryptone–sodium chloride solution was pour-plated on duplicate TSA plates. The plates were incubated at 37 $\pm$ 1°C for 24 h. All the experiments were repeated twice.

Preparation and inoculation of surfaces. Polypropylene and pine-wood cutting boards (of the kind routinely used in homes for food preparation) were bought at a local market and cut into 50 cm^2 portions. These test surfaces were washed with detergent (Procter and Gamble, Newcastle upon Tyne, UK) and rinsed in deionized water. Plastic surfaces were sterilized by autoclaving at 121°C for 20 min, and wood surfaces were sterilized under UV light for 12 h before use. Boards were immersed for 5 min in the

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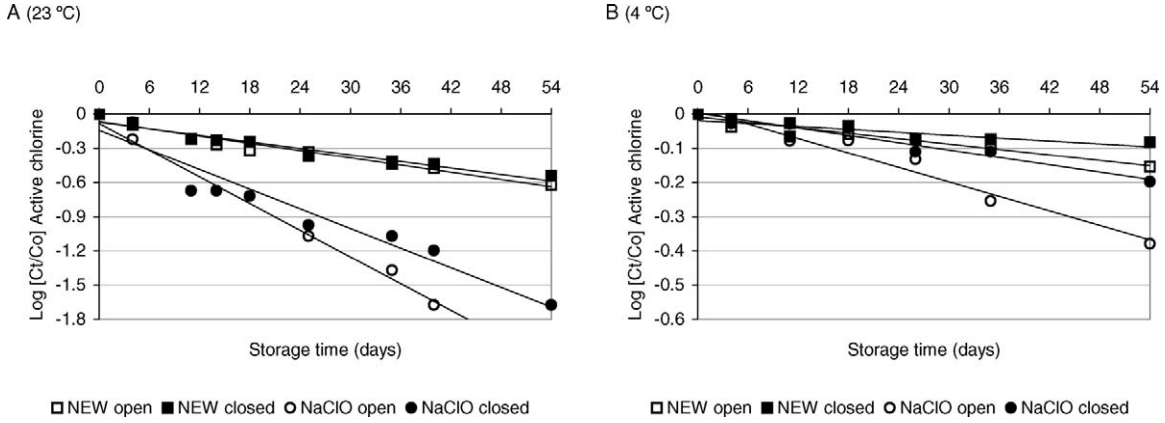

FIGURE 1. *Inactivation kinetics of active chlorine in neutral electrolyzed water (NEW; 445.82 ± 5.32 mg/liter of active chlorine) and sodium hypochlorite solution (NaClO; 334.36 ± 6.28 mg/liter of active chlorine) during 54-day storage, in open or closed conditions, at (A) room temperature (23 ± 2°C) or (B) 4 ± 2°C. Active chlorine values are expressed as log(Ct/Co), where Co is the initial chlorine concentration and Ct is the concentration at a given time.*

bacterial suspension and then dried in individual sterile metallic strainers under sterile air in a laminar flow cabinet for 20 min at room temperature (23 ± 2°C). The initial population on the surface was obtained by swabbing one face (50 cm^2) of an inoculated air-dried surface with a sterile cotton swab. The swab was washed in 5 ml of sterile tryptone–sodium chloride solution, and 1 ml of appropriate dilutions of this solution was plated onto duplicate TSA plates as described above.

Washing treatment. Inoculated surfaces were rinsed for 1 min (plastic boards) or 1 and 5 min (wooden boards) in individual sterile bags containing 250 ml of freshly prepared NEW or NaClO solutions, or sterile deionized water (control). After immersion, surfaces were removed with sterile tongues, and the population of each strain was determined on one face of the surface by swabbing. The swab was washed in 5 ml of neutralizing solution (sodium thiosulfate 0.5%), and appropriate dilutions of this solution were plated onto TSA plates. Immediately after removing the surface from the solution, 20% sodium thiosulfate was added to the washing solutions. After 5 min of neutralization, the number of viable cells in the washing solutions was determined on TSA plates. For enrichment, 5 ml of each treatment solution was transferred to 50 ml of tryptone soy broth (Panreac Química) and incubated 24 h at 37°C. All the experiments were conducted at room temperature (23 ± 2°C).

Data analysis. All cutting board trials were repeated at least four times. Microbial counts were expressed as log CFU per milliliter (washing solutions and inocula) or log CFU/50 cm^2 (surface). The reported values of plate count or physicochemical properties are the mean values over four individual trials ± standard deviations (SD). Data were subjected to analysis of variance and Duncan's multiple range tests by Statgraphics (Statistical Graphics Corporation, Englewood Cliffs, N.J.). Significant differences in plate-count data were established by the least significant difference at the 0.05 level of significance.

RESULTS

Storage experiments. The shelf life of pure NEW was compared with that of a NaClO solution, in open or closed conditions, at 4°C in a refrigerator with artificial light or at room temperature (23 ± 2°C) in the presence of natural light. The mean pH values for the NEW and NaClO solutions before storage were, respectively, 8.27 ± 0.21 and 9.23 ± 0.11; the respective ORP values were 774.0 ± 09.0 and 620.0 ± 07.0 mV; and the respective mean active chlorine concentrations were 445.82 ± 5.32 and 334.36 ± 6.28 mg/liter (values are the means of four measurements ± SD).

The degradation kinetics of active chlorine in NEW and NaClO solutions are shown in Figure 1. The half-life (time required for the active chlorine concentration to fall to half of its initial value) was calculated as the storage time (days) when log(Ct/Co) = −0.3. The active chlorine concentration decreased with time in all of the solutions, and this was accelerated by storing the solutions at room temperature in presence of natural light. In all storage conditions, the decrease in active chlorine concentration was higher in NaClO than in NEW solutions.

Storage at room temperature did not show a marked difference between open and closed conditions in both solutions. The active chlorine in NaClO solution was completely lost after 54 days of storage, and its half-life was approximately 6 days, compared with that of NEW of about 21 days (Fig. 1A). In solutions stored at 4°C, the chlorine loss was higher in open than in closed conditions and higher in NaClO than in NEW solutions. The half-life of active chlorine in NaClO stored in open bottles was about 45 days. NaClO in closed bottles and NEW (both in open and closed conditions) exhibited a half-life of more than 54 days (Fig. 1B).

The bactericidal activity of NEW and NaClO solutions stored under different conditions was evaluated following European Standard UNE-EN 1276 *(5)*. Pure cultures of about 7.5 log CFU/ml of *E. coli* were reduced to undetectable levels (as determined by a plating procedure) after 5 min of exposure to NEW or NaClO solutions stored for 54 days at 4°C, both in open or closed conditions. When solutions were stored at room temperature in the presence of natural light, NaClO lost its bactericidal activity after 26 days in open conditions (14 mg/liter of active chlorine) and after 39 days in closed conditions (21 mg/liter of active chlorine). However, no surviving bacteria were detected after treatment by NEW stored for 54 days (data not shown).

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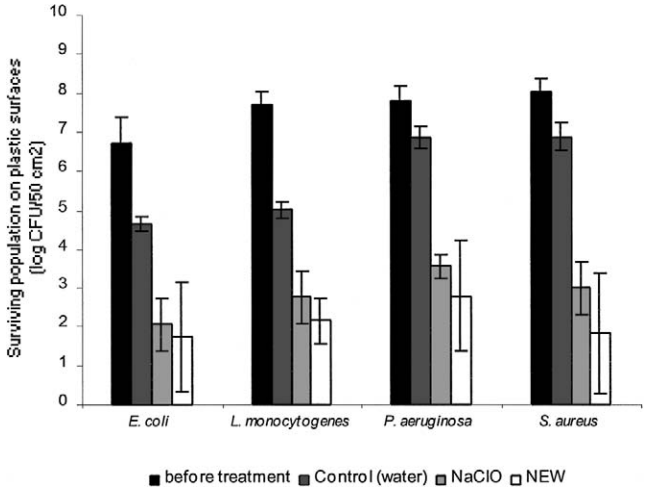

FIGURE 2. *Inactivation of* E. coli, L. monocytogenes, P. aeruginosa, *and* S. aureus *on plastic cutting boards after 1 min of treatment with neutral electrolyzed water (NEW; 64.11 ± 6.29 mg/liter of active chlorine) and sodium hypochlorite solution (NaClO; 62.32 ± 6.37 mg/liter of active chlorine) at 23 ± 2°C. Results are expressed as means ± SD of at least four repeated measurements.*

Cutting board experiments. The mean pH values for the NEW and NaClO solutions and the deionized water used in the cutting board study were, respectively, 7.76 ± 0.35, 8.11 ± 0.41, and 6.42 ± 0.53. The respective ORP values were 775.0 ± 10.0, 738.0 ± 15.0, and 648.0 ± 09.0. The mean active chlorine concentration of the NEW and NaClO solutions was, respectively, 64.11 ± 6.29 and 62.32 ± 6.37. No active chlorine was detected in deionized water. Values are the means of at least 16 measurements ± SD.

Figure 2 reports the results of the studies undertaken to determine the efficacy of NEW and NaClO solutions to inactivate *E. coli, L. monocytogenes, P. aeruginosa,* and *S. aureus* on plastic cutting boards. The mean population recovered from the surfaces (after 15 min of drying after inoculation) was between 6.73 and 8.03 log CFU/50 cm^2 for all strains. After washing plastic boards with NEW for 1 min, the bacterial populations on the surface were reduced by an average of 5 log CFU/50 cm^2, whereas the control treatment (deionized water) decreased the populations of all strains by 0.95 to 2.67 log CFU/50 cm^2.

The effectiveness of NEW was compared with that of a NaClO solution, but we found no significant difference ($P \geq 0.05$) between the bacterial counts after each treatment. Also, the populations of all strains after both treatments were very similar, without showing marked strain dependence.

Figure 3 shows the inactivation of *E. coli, L. monocytogenes, P. aeruginosa,* and *S. aureus* on wooden cutting boards after washing for 1 or 5 min in NEW or NaClO solution. The initial population of all strains on inoculated surfaces was between 7.68 and 8.68 log CFU/50 cm^2.

As observed in plastic boards, there was no significant difference ($P \geq 0.05$) between the final populations of all strains when comparing the effectiveness of washing with NEW or with a NaClO solution of similar pH, ORP, and active chlorine. The decrease in bacterial populations after washing contaminated wooden surfaces for 1 min in either treatment solution was less than 3 log CFU/50 cm^2 (Fig. 3A). For this reason, a new trial was made, increasing the exposure time for rinsing wooden surfaces to 5 min, and thus obtaining reductions of about 4 log CFU/50 cm^2 after soaking in either treatment solution (Fig. 3B). No significant reductions ($P \geq 0.05$) were obtained in the population of any strains, either after 1 or 5 min of washing inoculated wooden surfaces with the control solution (Fig. 3).

Table 1 shows the surviving populations of *E. coli, L. monocytogenes, P. aeruginosa,* and *S. aureus* in washing solutions after soaking plastic cutting boards for 1 min and wooden boards for either 1 or 5 min in 250 ml of NEW,

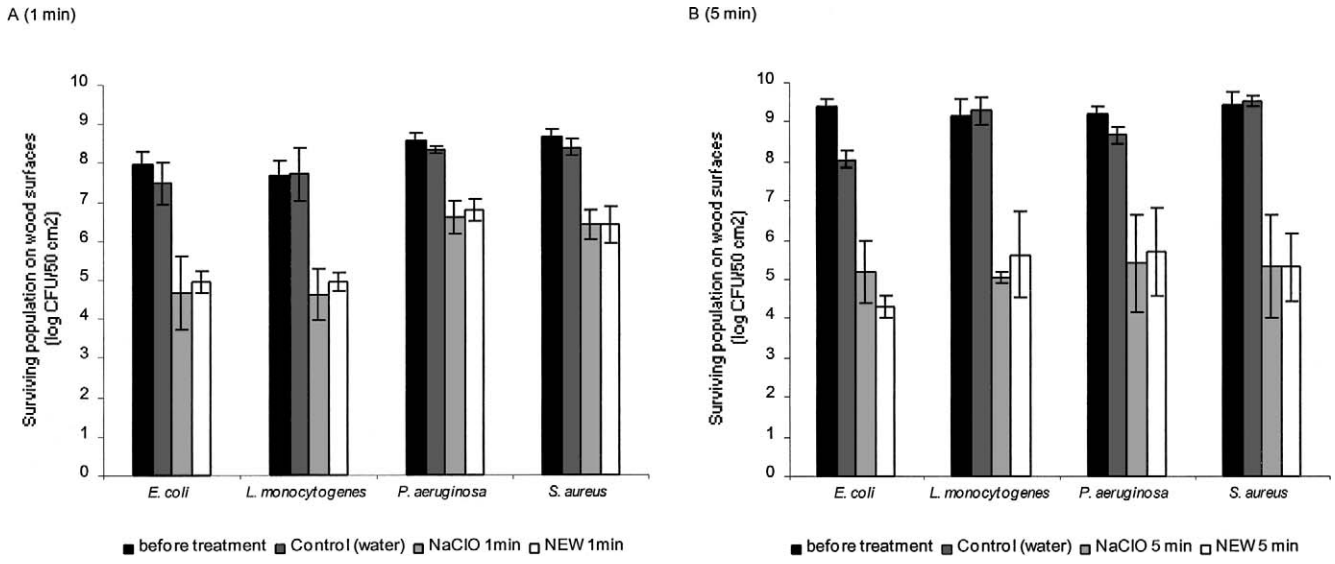

FIGURE 3. *Inactivation of* E. coli, L. monocytogenes, P. aeruginosa, *and* S. aureus *on wood cutting boards after washing for 1 min (A) or 5 min (B) in neutral electrolyzed water (NEW; 64.11 ± 6.29 mg/liter of active chlorine) and sodium hypochlorite solution (NaClO; 62.32 ± 6.37 mg/liter of active chlorine) at 23 ± 2°C. Results are expressed as means ± SD of at least four repeated measurements.*

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TABLE 1. *Surviving population of* E. coli, L. monocytogenes, P. aeruginosa, *and* S. aureus *in washing solutions (NEW, NaClO, and deionized water) after treatment of plastic and wooden cutting boards*[a]

Strain	Surface	Treatment time (min)	Population in wash solution after treatment (log CFU/ml)[b]		
			NEW	NaClO	Water (control)
E. coli	Plastic	1	ND[c]	ND	5.40 ± 0.75
	Wood	1	0.40 ± 0.80	0.19 ± 0.39	6.84 ± 0.31
		5	ND	ND	6.33 ± 0.39
L. monocytogenes	Plastic	1	0.33 ± 0.65	ND	5.41 ± 0.42
	Wood	1	0.18 ± 0.40	0.42 ± 0.61	6.35 ± 0.53
		5	ND	ND	6.94 ± 0.14
P. aeruginosa	Plastic	1	1.64 ± 1.45	1.05 ± 1.72	6.43 ± 0.27
	Wood	1	0.99 ± 0.69	1.67 ± 1.55	7.71 ± 0.52
		5	ND	ND	6.62 ± 0.44
S. aureus	Plastic	1	ND	0.24 ± 0.28	6.24 ± 0.30
	Wood	1	1.56 ± 1.48	1.73 ± 1.54	7.27 ± 0.12
		5	ND	ND	6.98 ± 0.19

[a] Values are the means of at least four repeated measurements ± SD.
[b] Cutting boards were immersed in 250 ml of treatment solution. The number of viable cells was determined by a direct plating procedure.
[c] ND, negative by an enrichment procedure; no detectable survivors by a direct plating procedure.

NaClO, or deionized water. No significant differences ($P \geq 0.05$) were found between treatments with NEW and NaClO solutions. After washing contaminated plastic boards for 1 min, the surviving bacterial populations in both treatment solutions were <1 log CFU/ml for all strains except *P. aeruginosa,* in which mean populations of 1.64 and 1.05 log CFU/ml were detected in NEW and NaClO washing solutions, respectively. After washing wooden surfaces for 1 min, the surviving populations of *E. coli* and *L. monocytogenes* in soaking solutions were <1 log CFU/ml. In wooden boards contaminated with *S. aureus* and *P. aeruginosa,* an average of 1.5 log CFU/ml was recovered in the treatment solutions. No survivors were detected in washing solutions after treating wooden cutting boards for 5 min with either NEW or NaClO. In control washing solution, an average of 6.54 log CFU/ml of all strains was recovered after treating both kinds of surfaces.

DISCUSSION

The bactericidal effectiveness of NEW on the surface of cutting boards has been assessed on four bacterial strains. Three of them (*E. coli, S. aureus,* and *P. aeruginosa*) are proposed in European Standard UNE-EN 1276 *(5)* for the evaluation of bactericidal activity of chemical disinfectants and antiseptics used in food, industrial, domestic, and institutional areas. The fourth, *Listeria monocytogenes,* is a foodborne pathogen of great concern as a cross-contaminant because it is able to attach to a variety of surfaces and multiply at room temperature or below *(10).* A previous study was carried out in our laboratories *(15)* to find the minimum concentration of NEW complying with European Standard UNE-EN 1276 *(5)*—that is, producing a population reduction of more than 5 log CFU/ml in all the evaluated strains in pure culture under clean conditions. On that basis, the NEW concentration chosen to evaluate its efficacy in reducing *E. coli, P. aeruginosa, S. aureus,* and *L. monocytogenes* on plastic and wooden cutting boards was such to contain 63 mg/liter of active chlorine.

In this study, washing of contaminated cutting boards in NEW for 1 min revealed a significant difference ($P \leq 0.05$) between the decontamination of plastic and wooden surfaces. After treating plastic boards, initial bacterial populations of approximately 7.5 log CFU/50 cm^2 decreased by approximately 5.4 log CFU/50 cm^2. In wooden boards instead, the same treatment reduced the initial bacterial populations by 2.5 log CFU/50 cm^2, and when the treatment time was increased to 5 min, populations were reduced by about 4 log CFU/50 cm^2 after soaking in NEW. This difference between both types of surface was also observed in the control treatment: washing contaminated plastic surfaces with sterile deionized water decreased the populations of all strains by about 1.7 log CFU/50 cm^2, whereas the same treatment on wooden boards yielded no significant differences. An explanation could be that wooden boards readily absorbed the bacterial suspension during the 5-min inoculation step; thus, although the surface appeared dry after 20 min of drying under sterile air, the inner part of the wood still remained wet, retaining most of the bacteria. These findings are in agreement with the results of Welker et al. *(34)* and Boucher et al. *(9).*

The results also show that NEW has a broad spectrum of action over the chosen strains: the reductions underwent by all the populations after the same treatment time showed no significant difference ($P \geq 0.05$). Moreover, this was the case on both materials.

NaClO is one of the most widely used disinfectants in household sites and food industries. In this study, the effectiveness of NEW was compared with that of NaClO solution with the same active chlorine content and with similar pH and ORP. The obtained results reveal that the bactericidal efficacy of NEW on plastic and wooden surfaces is similar to that of NaClO.

The disinfection efficacy of NEW compared with NaClO treatment was also assessed in the washing solutions after treating both surfaces. In this respect, the mean surviving populations of all bacteria in NEW and NaClO

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washing solutions were <1 log CFU/ml after soaking both surfaces for 1 min; and in wooden boards, no survivors were detected after a 5-min treatment. This suggests that NEW could prevent cross-contamination from treatment solutions. In contrast, an average of 6.45 log CFU/ml of all strains was recovered in the control water after washing.

Compared with NaClO, NEW is less hazardous for workers and environment because it is produced by using only salt, tap water, and electricity, and no concentrated chemicals must be handled. In addition, NEW also has the advantage of being generated on site, thus reducing transport and storage problems. It is conceivable that household and food service kitchens could dispose of an electrolysis device in the near future; but until freshly prepared NEW becomes widely available, it may be necessary to store the solution. We thus evaluated the shelf lives of NEW (446 mg/liter of active chlorine) and of NaClO solutions (334 mg/liter of active chlorine) during a 54-day period under the following storage conditions: at 4°C under artificial light, and at room temperature in presence of natural light, both in open and closed bottles. In this study, NEW exhibited more durability than NaClO in all of the evaluated conditions in terms of active chlorine degradation and bactericidal activity. These facts lead us to suggest that NEW be considered as a suitable alternative to NaClO for the disinfection of food contact surfaces.

In conclusion, this study revealed that NEW treatment could be used as an effective method for reducing microbial contamination on plastic and wooden kitchen cutting boards. NEW was also revealed to have a broad spectrum of action over the evaluated strains on both types of surfaces. The obtained results also suggest that the wooden boards we evaluated are not a suitable option for food preparation because they are very difficult to clean.

NEW's efficacy in reducing bacterial populations on both surfaces was comparable to that of a NaClO solution of similar pH, ORP, and active chlorine concentration. Also, the reductions obtained in this study were equal to or better than results obtained by immersing different food contact surfaces in AEW of similar active chlorine content *(23, 32).* These results, together with those previously obtained in treating stainless steel and glass surfaces *(15),* show that NEW is an efficient alternative for the disinfection of various types of food contact surfaces, with the advantage of having a longer storage time.

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REFERENCES

1. Ak, N. O., D. O. Cliver, and W. K. Charles. 1994. Cutting boards of plastic and wood contaminated experimentally with bacteria. *J. Food Prot.* 57:16–22.
2. Ak, N. O., D. O. Cliver, and W. K. Charles. 1994. Decontamination of plastic and wooden cutting boards for kitchen use. *J. Food Prot.* 57:23–30.
3. Altekruse, S. F., S. Yang, B. B. Timbo, and F. J. Angulo. 1999. A multi-state survey of consumer food-handling and food-consumption practices. *Am. J. Prev. Med.* 16:216–221.
4. American Public Health Association. 1998. 4500-Cl B. Chlorine (residual). Iodometric method I, p. 4-55–4-56. *In* Standard methods for the examination of water and wastewater, 20th ed. American Public Health Association, American Water Works Association, and Water Environment Federation, Washington, D.C.
5. Anonymous. 1998. European standard UNE-EN 1276. Chemical disinfectants and antiseptics: quantitative suspension test for the evaluation of bactericidal activity of chemical disinfectants and antiseptics used in food, industrial, domestic, and institutional areas—test method and requirements (phase 2, step 1). AENOR, Madrid.
6. Ayebah, B., and Y.-C. Hung. 2005. Electrolyzed water and its corrosiveness on various surface materials commonly found in food processing facilities. *J. Food Process Eng.* 28:247–264.
7. Ayebah, B., Y.-C. Hung, and J. F. Frank. 2005. Enhancing the bactericidal effect of electrolyzed water on *Listeria monocytogenes* biofilms formed on stainless steel. *J. Food Prot.* 68:1375–1380.
8. Beumer, R. R., and H. Kusumaningrum. 2003. Kitchen hygiene in daily life. *Int. Biodeterior. Biodegrad.* 51:299–302.
9. Boucher, S. N., A. H. L. Chamberlain, and M. R. Adams. 1998. Enhanced survival of *Campylobacter jejuni* in association with wood. *J. Food Prot.* 61:26–30.
10. Chmielewski, R. A. N., and J. F. Frank. 2003. Biofilm formation and control in food processing facilities. *Compr. Rev. Food Sci. Food Saf.* 2:22–32.
11. Clarkson, R. M., and A. J. Moule. 1998. Sodium hypochlorite and its use as an endodontic irrigant. *Aust. Dent. J.* 43:250–256.
12. Cogan, T. A., J. Slader, S. F. Bloomfield, and T. J. Humphrey. 2002. Achieving hygiene in the domestic kitchen: the effectiveness of commonly used cleaning procedures. *J. Appl. Microbiol.* 92:885–892.
13. Cools, I., M. Uyttendaele, J. Cerpentier, E. D'Haese, H. J. Nelis, and J. Debevere. 2005. Persistence of *Campylobacter jejuni* on surfaces in a processing environment and on cutting boards. *Lett. Appl. Microbiol.* 40:418–423.
14. Deza, M. A., M. Araujo, and M. J. Garrido. 2003. Inactivation of *Escherichia coli* O157:H7, *Salmonella enteritidis* and *Listeria monocytogenes* on the surface of tomatoes by neutral electrolyzed water. *Lett. Appl. Microbiol.* 37:482–487.
15. Deza, M. A., M. Araujo, and M. J. Garrido. 2005. Inactivation of *Escherichia coli, Listeria monocytogenes, Pseudomonas aeruginosa* and *Staphylococcus aureus* on stainless steel and glass surfaces by neutral electrolysed water. *Lett. Appl. Microbiol.* 40:341–346.
16. Kim, C., Y.-C. Hung, and R. E. Brackett. 2000. Efficacy of electrolyzed oxidizing (EO) and chemically modified water on different types of foodborne pathogens. *Int. J. Food Microbiol.* 61:199–207.
17. Kim, C., Y.-C. Hung, R. E. Brackett, and J. F. Frank. 2001. Inactivation of *Listeria monocytogenes* biofilms by electrolyzed oxidizing water. *J. Food Process Preserv.* 25:91–100.
18. Klontz, K. C., B. Timbo, S. Fein, and A. Levy. 1995. Prevalence of selected food consumption and preparation behaviours associated with increased risks of foodborne disease. *J. Food Prot.* 58:927–930.
19. Len, S.-V., Y.-C. Hung, D. Chung, J. L. Anderson, M. C. Erickson, and K. Morita. 2002. Effects of storage conditions and pH on chlorine loss in electrolyzed oxidizing (EO) water. *J. Agr. Food Chem.* 50:209–212.
20. Marais, J. T. 2000. Cleaning efficacy of a new root canal irrigation solution: a preliminary evaluation. *Int. Endod. J.* 33:320–325.
21. Marais, J. T., and V. S. Brözel. 1998. Electro-chemically activated water in dental unit water lines. *Br. Dent. J.* 187:154–158.
22. Nagamatsu, Y., K.-K. Chen, K. Tajima, H. Kakigawa, and Y. Kozono. 2002. Durability of bactericidal activity in electrolyzed neutral water by storage. *Dent. Mater. J.* 21:93–104.
23. Park, H., Y.-C. Hung, and C. Kim. 2002. Effectiveness of electrolyzed water as a sanitizer for treating different surfaces. *J. Food Prot.* 65:1276–1280.
24. Rossoni, E. M. M., and C. C. Gaylarde. 2000. Comparison of sodium hypochlorite and peracetic acid as sanitising agents for stainless steel food processing surfaces using epifluorescence microscopy. *Int. J. Food Microbiol.* 61:81–85.
25. Ryan, M. J., P. G. Wall, R. J. Gilbert, M. Griffin, and B. Rowe. 1996. Risk factors for outbreaks of infectious intestinal disease

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linked to domestic catering. *Commun. Dis. Rep. CDR Rev.* 6:R179–R183.
26. Schönwälder, A., R. Kehr, A. Wulf, and K. Smalla. 2002. Wooden boards affecting the survival of bacteria? *Holz Roh- Werkst.* 60:249–257.
27. Taylor, J. H., S. J. Rogers, and J. T. Holah. 1999. A comparison of the bactericidal efficacy of 18 disinfectants used in the food industry against *Escherichia coli* O157:H7 and *Pseudomonas aeruginosa* at 10 and 20°C. *J. Appl. Microbiol.* 87:718–725.
28. Tirado, C., and K. Schmidt. 2001. WHO surveillance programme for control of foodborne infections and intoxications: preliminary results and trends across greater Europe. *J. Infect.* 43:80–84.
29. U.S. Environmental Protection Agency. 1999. Disinfectant use in water treatment, chap. 2. *In* Alternative disinfectants and oxidants. EPA guidance manual 815-R-99-014. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. Available at: http://www.epa.gov/safewater/mdbp/alternative_disinfectants_guidance.pdf. Accessed 9 February 2006.
30. U.S. Food and Drug Administration. 1997. On the home front. Available at: http://www.fda.gov/fdac/features/1997/797_home.html. Accessed 9 February 2006.
31. Venkitanarayanan, K. S., G. O. I. Ezeike, Y.-C. Hung, and M. P. Doyle. 1999. Efficacy of electrolyzed oxidizing water for inactivating *Escherichia coli* O157:H7, *Salmonella enteritidis* and *Listeria monocytogenes. J. Food Prot.* 65:4276–4279.
32. Venkitanarayanan, K. S., G. O. I. Ezeike, Y.-C. Hung, and M. P. Doyle. 1999. Inactivation of *Escherichia coli* O157:H7 and *Listeria monocytogenes* on plastic kitchen cutting boards by electrolyzed oxidizing water. *J. Food Prot.* 62:857–860.
33. Watchel, M. R., J. L. McEvoy, Y. Luo, A. M. Williams-Campbell, and M. B. Solomon. 2003. Cross-contamination of lettuce (*Lactuca sativa* L.) with *Escherichia coli* O157:H7 via contaminated ground beef. *J. Food Prot.* 66:1176–1183.
34. Welker, C., N. Faiola, S. Davis, I. Maffatore, and C. A. Batt. 1997. Bacterial retention and cleanability of plastic and wood cutting boards with commercial food service maintenance practices. *J. Food Prot.* 60:407–413.

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