Journal of Food Protection, Vol. 70, No. 3, 2007, Pages 648–654

Evaluation of Hot-Water and Sanitizer Dip Treatments of Knives Contaminated with Bacteria and Meat Residue

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MS 06-387: Received 18 July 2006/Accepted 1 October 2006

ABSTRACT

Hot water (HW; 82.2°C, 180°F) is used for sanitation of meat cutting implements in most slaughter facilities, but validation of actual practices against meat-borne bacterial pathogens and spoilage flora is lacking. Observed implement immersions in HW in two large pork processing plants were found to typically be ≤1 s. Impact of these practices on bacteria on metal surfaces was assessed in the laboratory, and alternative treatments were investigated. Knives were inoculated with raw pork residues and *Escherichia coli* O157:H7, *Salmonella* Typhimurium DT104, *Clostridium perfringens,* and *Lactobacillus* spp. and were sampled before and after 1- or 15-s dips of blades in HW, warm water (48.9°C), or warm sanitizers (neutral or acid quaternary ammonium compounds [QAC] at 400 ppm, or peroxyacetic acid at 700 ppm H_2O_2 and 165 ppm peroxyacetic acid). Simultaneous scrubbing and 15-s dipping in HW or acid QAC was also evaluated. Reductions on knives dipped for 1 s were usually <1 log and were not significantly different ($P > 0.05$) between treatments. Reductions of *E. coli* O157:H7 after 15 s in HW, neutral QAC, acid QAC, or peroxyacetic acid were 3.02, 2.38, 3.04, and 1.52 log, respectively. Reductions of other bacteria due to HW were not significantly different from sanitizers and were significantly greater than warm water for all bacteria except *C. perfringens.* Combined scrubbing and 15-s dipping in HW resulted in a 2.91- and 2.25-log reduction of *E. coli* O157:H7 and *Salmonella* Typhimurium DT104, respectively, whereas reduction caused by acid QAC was significantly less at about 1.7 log each. Brief dip treatments of contaminated knives have limited efficacy, but longer immersions cause greater reductions that were not enhanced by scrubbing. QAC is a suitable alternative to HW in this application.

The microflora of raw meat just after slaughter may include a number of enteropathogens, primarily originating from the gastrointestinal tract of the animals. *Salmonella (17)* and *E. coli (14, 20)* are notable residents of the flora of porcine and bovine slaughter animals. Enterohemorrhagic *E. coli* and *Salmonella* are of primary interest due to their pathogenicity and prior history of meat-borne transmission to humans *(26),* but numerous other nonpathogenic bacteria are also present *(2, 7)*. In-process sanitizing treatments are generally intended to provide one of many hurdles over cross-contamination from spoilage microorganisms or bacterial pathogens. Because the lack of a true bacteriocidal treatment of carcasses and postslaughter raw meat limits the possibility to reduce counts of or control spread of these bacteria, the contamination of carcasses by pathogens is difficult, if not impossible, to eliminate *(1)*. Carcass wash treatments have shown some effectiveness in reducing populations of enteric pathogens *(3, 18)* and spoilage bacteria *(8),* but no treatment can completely free the meat from all bacteria. Therefore, it is beneficial to limit spread of bacteria from one carcass or cut to the next. Failure to properly clean and sanitize equipment such as cutting tables, grinders, and knives has been identified as the primary cause of excessive bacterial contamination of meat *(25)*.

Various types of sanitizing treatments are relied on to reduce microbial contamination on freshly slaughtered animal carcasses and cuttings as well as on product contact surfaces. Chemical sanitization regimens for processing equipment and product contact surfaces occur during entire shifts and may occur during production hours at mid-shift breaks. In addition, chemical sanitization is used during production when processing implements and machines such as knives, neck splitters, bung tiers, and saws are sanitized by dipping into containers of hot water adjacent to processing lines. These treatments are intended to reduce carcass-to-carcass spread of pathogenic and spoilage bacteria. Large-scale, high-speed (1,000 pork head per h) animal slaughter and raw-meat processing dictates that each step engenders a minimal amount of resources and time in order to successfully compete in the market. Food safety or quality-related interventions, while of utmost importance, must also fit these criteria. Such interventions are also more likely to be properly adhered to if they are realistic, practical, and impart minimal impact on efficient and rapid meat processing.

In the United States, treatment of raw meat implements by 82.2°C (180°F) was once required by the U.S. Department of Agriculture (USDA)–Food Safety Inspection Service to mitigate risk of spread of bacterial contaminants during handling of diseased carcasses or parts *(22)*. Although provision was also made for the use of disinfectants for this purpose, hot water became more widely used. Therefore, use of hot water is familiar and generally still encouraged by USDA field inspection personnel. Due to

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the high speed at which lines operate, the critical component of treatment time may be unobserved by line workers. The limitations and inadequacies of hot water have been demonstrated by several researchers. When there is organic matter present on equipment, such as would occur during slaughter or processing operations, the disinfection ability of 180°F water is reduced *(13, 19)*. Peel and Simmons *(15)* reported that 82.2°C water eliminated *Salmonella* Typhimurium on steel after 2 s, but that the time for elimination was increased to a minimum of 6 s when organic matter was introduced. Hot water also has a tendency to cause coagulation of protein, which cooks organic material onto equipment surfaces and leads to more difficulty in removing meat residues *(13, 24)*. As meat residues are retained on equipment due to use of 82.2°C hot water, microorganisms like *Salmonella (16)* can become protected from sanitizing treatments.

Although sanitizing dip treatments using hot water are used throughout the meat processing industry, there is a misconception about the true effectiveness of the treatments. Therefore, the objective of this study was to assess the degree of inactivation of bacteria—particularly foodborne pathogens—resulting from simulation of brief in-process applications of hot water to knives. A second objective was to compare sanitizer solutions as alternative treatments with current sanitation practices for implements relying on hot-water dipping.

MATERIALS AND METHODS

Observation of implement immersion in plants. Knife or equipment hot-water immersion events were observed on three separate occasions by the authors on the kill floors in two large pork slaughter plants located in the upper Midwest region of the United States. Tabulations were made of the use of hot water for immersion of meat cutting or processing implements at four stations: stick-bleeding knives, neck-splitter machines, head-dropper knives, and bung-tier machines. At each of those stations, hot-water tanks intended for immersion were >83°C as determined by a calibrated digital thermometer. Workers were observed until their repetitive motion for dipping their implements was consistent or until they became aware that they were being observed. Dip-coverage percentages were based on visual estimation by the observer of the percent of the knife or machine part that was immersed. Inconsistent dipping motions were tabulated as the least–dip-coverage percentage observed. The number of hog carcasses skipped between hot-water immersion events was also noted at each station.

Inocula. Cultures of *E. coli* O157:H7 (strains SEA13B88 [clinical isolate from apple cider consumption], E0139 [venison jerky], 302C4 [salami], and E0018 [calf fecal isolate]) and multidrug-resistant *Salmonella* Typhimurium DT104 were kindly provided by Dr. Larry Beuchat, Center for Food Safety, University of Georgia, Griffin. These strains were grown at 37°C for 18 to 24 h in tryptic soy broth (pH 7.2; Difco, Becton Dickinson, Sparks, Md.). Actively growing cultures of *C. perfringens* strains FD1041 and ATCC 12916 (fluid thioglycollate medium [pH 7.8; Difco, Becton Dickinson]) were transferred (1 ml) to freshly steamed modified Duncan-Strong sporulation medium with caffeine and incubated at 37°C for 24 h. *Lactobacillus sakei* subsp. *sakei* and *Lactobacillus curvatus* were grown for 18 to 24 h at 37°C in deMan Rogosa Sharpe broth (pH 6.5; Difco, Becton Dickinson). Confirmation that populations of *E. coli* O157:H7, *Salmonella* Typhimurium, *C. perfringens,* and *Lactobacillus* spp. exceeded 6 log CFU/ml of broth was done by spiral plating (model D, Spiral Systems, Inc., Cincinnati, Ohio) on modified eosin methylene blue agar, Hektoen enteric agar, Shahidi-Ferguson perfringens agar, and *Lactobacillus* deMan Rogosa Sharpe medium, respectively. Methylene blue agar and Hektoen enteric agar plates were incubated aerobically at 37°C for 24 h, whereas Shahidi-Ferguson perfringens agar and deMan Rogosa Sharpe plates were incubated anaerobically for 48 and 72 h, respectively, prior to counting characteristic colonies.

Simulated knife contamination. Fresh boneless raw pork butts, having a fat and a lean side, were obtained from the same plants where implement immersion observations were made. Pork butts were chilled, vacuum packaged, and shipped in coolers to the laboratory to arrive the morning after production. Packages were stored at 4.4°C for no more than 1 week prior to opening and using. Newly manufactured meat-cutting knives were selected that were identical to those used on the kill floor of one of the pork slaughter plants (Forschner, Ibach, Switzerland). The surface area of either side of the knives was determined to be 17 cm^2. Knives were cleaned with soap and water, and autoclaved before each use.

One hundred milliliters of each broth culture containing log-phase vegetative cells of all cultures listed above and *C. perfringens* spores was poured into a large plastic bucket with ca. 20-liter capacity. Raw pork butt surfaces were co-inoculated by dipping into the bucket containing the cultures. The meat was removed from the inoculum and set onto a plastic cutting board. One vertical slice was made with knives into inoculated pork deep enough until the entire blade contacted meat. Slices on fat or lean sides were alternated with replicates. This knife-blade inoculation was intended to simulate an in-plant scenario whereby a production line worker's blade would contact meat residues and bacteria during a cut. The inoculation method was designed to distribute meat residue and to achieve ≥2.0-log CFU of each bacterial species/cm^2 of blades so that reductions by treatment could be measured.

Knife sampling method. Six replicate experiments were carried out to validate the sampling method used in the study. Three methods of recovering bacteria from inoculated knives were compared: hydrated cotton towelette, hydrated sponge, and hydrated calcium alginate swab. Dehydrated sterile polyurethane sponges in Whirl-Pak bags (B01245WA, Nasco, Modesto, Calif.) and autoclaved cotton towelettes that were aseptically placed in Whirl-Pak bags were hydrated with 10 ml of Dey/Engley neutralizing broth (pH 7.6; Difco, Becton Dickinson) prior to use. Calcium alginate swabs (171KS01, Copan, Corona, Calif.) were hydrated in 4.5 ml of Dey/Engley neutralizing broth plus 1% (wt/vol) sodium citrate immediately prior to sampling of knives. Sampling involved thoroughly wiping entire surfaces of a side of inoculated knives with hydrated towelettes, sponges, or swabs. Swabs were applied cross-directionally according to accepted methods *(4)*. Towelettes and sponges were placed into small stomacher bags containing 90 ml of phosphate-buffered saline (pH 6.8), and were pummeled for 1 min at medium speed in a stomacher (model 400, Seward, London, UK). Swabs were immersed back into a test tube containing the 10 ml of Dey/Engley neutralizing broth buffer and vortexed vigorously for 1 min. Stomached or vortexed liquids were further diluted with phosphate-buffered saline as needed prior to spiral plating onto selective agar media as listed above or onto tryptic soy agar (pH 7.3; Difco, Becton Dickinson) for enumeration of aerobic mesophiles after incubation at 37°C for 24 h.

All subsequent knife sampling was conducted using the hydrated sponge method based on results of this sampling method comparison.

Sanitizing treatments. Hot water (HW; 82.2°C, 180°F) and warm water (WW; 48.9°C, 120°F) were evaluated as control treatments compared with three sanitizing agents, each at 48.9°C (120°F). Highest nonrinse use concentrations permitted on food contact surfaces by the USDA of peroxyacetic acid (PAA; 165 ppm peracetic acid and 700 ppm H_2O_2), 4-alkyl chain quaternary ammonium (QAC; 400 ppm), and 4-alkyl chain acid quaternary ammonium (acid QAC; 400 ppm) (Saratoga Specialties, Elmhurst, Ill.) were used in this study. The approved sanitizers were selected for evaluation based on efficacy against bacteria at elevated temperatures (including 48.9°C), stability of active ingredients, soil tolerance, and lack of staining. The treatment temperature was also chosen because it would cause melting of lipids but was low enough to limit protein coagulation on metal surfaces during sanitizer application. To prepare sanitizing solutions, stainless steel cylindrical beakers (outside diameter, 15.6 mm; 22.5 mm high) were filled with 4 liters of deionized water. Appropriate amounts of concentrated sanitizing solutions were added to the water to achieve target concentrations of active components according to the manufacturer's instructions. Concentrations of chemicals were verified using a QAC test kit (model QT-DR, LaMotte, Chestertown, Md.) or PAA kit (model 3006119, Saratoga Specialties). Sanitizer solutions in containers were heated using hot plates until temperatures reached 48.9 ± 1°C according to alcohol-in-glass thermometers. Separate beakers were prepared with only deionized water and were heated to 82.2 ± 1 or 48.9 ± 1°C for HW and WW controls, respectively.

The left side of contaminated knife blades was sampled before submersion in treatment solutions with the hydrated sponge method described above. Preliminary work demonstrated that there was no significant difference ($P > 0.05$) between populations of bacteria recovered from left and right sides of contaminated knives (data not shown). Knives were then completely submerged in treatment solutions for 1 s to simulate in-plant treatments or 15 s to demonstrate an improvement with treatment time, or for 15 s combined with scrubbing. To achieve scrubbing action, two store-bought, hard-plastic, bristled scrub brushes were fashioned together such that the bristles of each brush touched. These scrub brushes were completely submerged into containers of HW or sanitizer so that knives were scrubbed as they were submerged and removed from treatment solution. Upon removal of knives from treatment solutions, the right sides were immediately sampled with the sponge, and bacteria were enumerated from sponges. After incubating and counting plates, mean log reductions were calculated by subtracting mean log populations after treatment from mean log populations before treatment.

Statistical analyses. Six replicates were performed of the knife-sampling method comparison and the 1-s dip treatments in HW or sanitizers. Three replicates were performed for all 15-s treatments, with or without scrubbing. Microbiological data were transformed to log values, and posttreatment values were subtracted from pretreatment values to get log reductions. Log reductions were then subjected to two-way repeated measures analysis of variance followed by a post-hoc Duncan's multiple range test for comparing means log reductions at the $\alpha = 0.95$ level (SigmaStat, version 2.03, SPSS, Inc., Chicago, Ill.).

RESULTS

Implement immersion practices. Percentages of implement coverage by HW during immersion observed in two large pork slaughter facilities is shown in Figure 1. All immersion events were completed in 1 s or less, and all HW tanks were >83°C. Complete (100%) immersion of implements occurred less than 20% of the time with stick knives, neck-splitter machines, and bung-tier machines, whereas head dropper knives were completely immersed just over 30% of the time. Generally, most immersion events resulted in between 50 and 100% coverage of the implement. At each station less than 50% implement coverage occurred more often than 100% coverage except for bung-tier machines, which had HW tanks specially fitted to facilitate immersion of almost the entire length of the machine. USDA personnel inspecting dropped heads only immersed knives at breaks and not between carcasses. For all personnel using knives, sharpening steels were only immersed periodically, but were thoroughly rinsed in sinks along with knives randomly about four times each hour. The number of pig carcasses skipped between immersion events was also tabulated. Some workers allowed several carcasses (up to five) to pass between immersion events, whereas others allowed few (one to three). Generally, those workers performing the head-dropping operation with knives were most likely to cut on carcasses without having immersed knives. As many as five carcasses were cut without immersion of implements at these stations.

Knife sampling method. As reported in Table 1, no significant differences ($P > 0.05$) were seen between sampling methods for recovery of aerobic mesophiles, *E. coli* O157:H7, *Salmonella* Typhimurium, *C. perfringens,* and *Lactobacillus* spp. Mean levels of aerobic mesophiles recovered on tryptic soy agar from knives sampled with the towelettes, sponges, and swabs were 4.30, 4.60, and 4.46 log CFU/cm^2, respectively. These closely matched populations of *E. coli* O157:H7 recovered from knives by either method. *Salmonella* Typhimurium was enumerated from knives by the towelette, sponge, and swab methods at 3.40, 3.83, and 3.86 log CFU/cm^2, respectively. *Lactobacillus* spp. were enumerated at similar levels (i.e., close to 4 log CFU/cm^2), while *C. perfringens* was found at ca. 2 log CFU/cm^2. Spores of *C. perfringens* were not optimally recovered from knives because no heat shock was applied.

Knife sanitizing treatments. Laboratory simulation of observed implement sanitation practices during production (1-s immersion at 82.2°C) revealed that about a 0.5- and 2-log reduction of foodborne pathogens can be achieved (Table 2). Reductions on knives dipped for 1 s were usually <1 log and were not significantly different ($P > 0.05$) between treatments for any of the groups of bacteria tested. One-second immersion in sanitizers or WW was not significantly different ($P > 0.05$) from HW immersion. Reductions of *C. perfringens* cells were slightly higher than those of other bacteria.

Reductions of *E. coli* O157:H7 after 15 s in HW, neutral QAC, acid QAC, or PAA were 3.02, 2.38, 3.04, and 1.52 log, respectively (Table 3). At the 15-s treatment time, reductions of other bacteria due to HW were not significantly different from sanitizers and were significantly greater than was WW for all bacteria except *C. perfringens.*

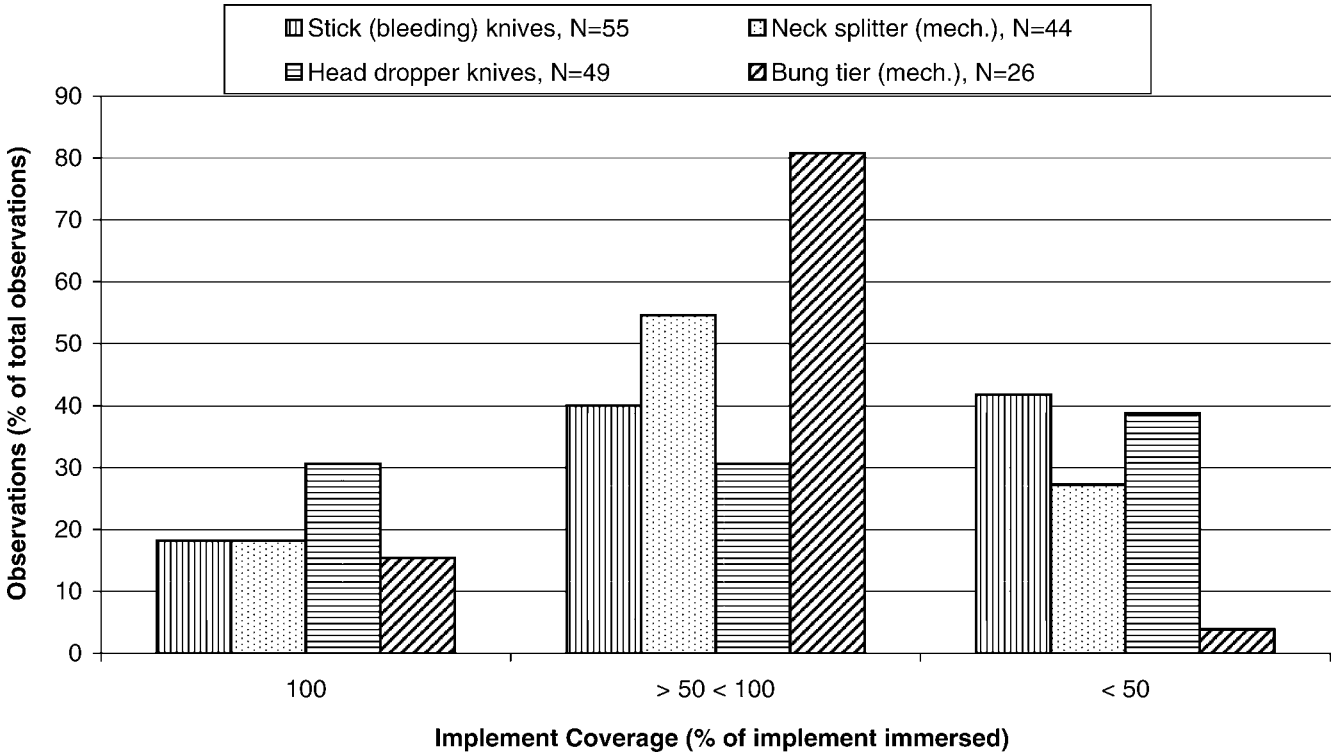

FIGURE 1. *Survey of implement immersion in hot water (82.2°C) in two large pork processing plants. A total of three workers were observed, each using stick knives, neck splitters, and bung tiers. Six head-dropper knife workers were observed. A total of four U.S.D.A. inspectors were observed only rinsing implements in hot water before breaks. Hot-water dips were all >82.2°C, and dip times were all <1 s.*

Fifteen-second immersion in HW or 400 ppm acid QAC caused significantly greater reduction of *E. coli* O157:H7 than did 15 s in PAA. There were no significant differences between 15-s treatments with HW and sanitizers for all other bacteria.

The combination of scrubbing with 15-s dipping in HW resulted in a 2.91- and 2.25-log reduction of *E. coli* O157:H7 and *Salmonella* Typhimurium DT104, respectively, whereas reduction caused by acid QAC was significantly less at about 1.7 log for each pathogen (Table 4). The 15-s immersion in HW plus scrubbing caused significantly more reduction of aerobic mesophiles, *E. coli* O157:H7, and *Salmonella* Typhimurium DT104 than did the same treatment with acid QAC at 48.9°C. There were no significant differences in reductions of *C. perfringens* and *Lactobacillus* spp. on knives resulting from HW-scrubbing or acid QAC–scrubbing treatments.

DISCUSSION

The observations made in two plants strongly suggest that sanitization treatments applied to equipment and utensils during high-speed large-animal slaughter are brief and often incomplete. It was also observed that >82°C is consistently maintained on the kill floor, although negative implications of using HW included elevated air temperatures and condensation on overhead surfaces. Uniform, albeit incomplete, immersion of implements was well controlled at bung-tier stations where immersion tanks were designed to fit those apparatuses. This design may be modified to enhance coverage and could be used at other processing stations to encourage uniform and complete immersion of most implements.

As shown in Table 1, the knife contamination method used in this study resulted in highest populations of *E. coli* O157:H7 on knives, followed by nearly equal levels of *Sal-*

TABLE 1. *Comparison of sampling methods for recovery of bacteria from surfaces of inoculated knives*

Sampling method	Mean no. of bacteria recovered ± SD (log CFU/cm^2)[a]				
	Aerobic mesophiles	*Escherichia coli* O157:H7	*Salmonella* Typhimurium DT104	*Clostridium perfringens*	*Lactobacillus* spp.
Hydrated cotton towelette	4.30 ± 0.53	4.31 ± 0.48	3.40 ± 0.48	2.12 ± 0.37	3.74 ± 0.48
Hydrated sponge	4.60 ± 0.29	4.54 ± 0.27	3.83 ± 0.28	2.44 ± 0.36	3.62 ± 0.59
Hydrated calcium alginate swab	4.46 ± 0.36	4.41 ± 0.35	3.86 ± 0.57	2.22 ± 0.23	4.64 ± 0.70[b]

[a] No significant differences ($P > 0.05$) between treatments within bacteria type.
[b] Two missing values for this parameter.

TABLE 2. *Log reductions of pathogenic and spoilage bacteria on contaminated knife blades achieved by various 1-s sanitizing treatments*

Treatment[a]	Mean log reductions of bacteria ± SD[b]				
	Aerobic mesophiles	*Escherichia coli* O157:H7	*Salmonella* Typhimurium DT104	*Clostridium perfringens*	*Lactobacillus* spp.
82.2°C/180°F, hot water (HW)	0.98 ± 0.26	0.84 ± 0.29	1.13 ± 0.36	1.36 ± 0.41	0.85 ± 0.61
48.9°C/120°F, warm water (WW)	0.47 ± 0.65	0.54 ± 0.68	0.84 ± 1.05	0.87 ± 0.84	0.53 ± 0.60
440 ppm SS 4 quat (QAC)	0.63 ± 0.48	0.77 ± 0.60	0.61 ± 0.83	2.04 ± 0.49	0.97 ± 0.54
440 ppm SS 4 acid quat (acid QAC)	0.57 ± 0.20	0.59 ± 0.26	0.91 ± 0.18	1.96 ± 1.39	0.46 ± 0.89
165 ppm peracetic acid and 700 ppm H_2O_2 (PAA)	0.71 ± 0.95	0.66 ± 1.05	0.75 ± 1.10	1.50 ± 0.90	0.69 ± 0.98

[a] Sanitizing treatments consisted of a 1-s dip of the entire blade into HW or sanitizers. Sanitizers were tested at 48.9°C (120°F) at the highest concentrations approved for nonrinsed treatment of food contact surfaces.

[b] Log reductions represent mean differences between log counts on various agar media before and after treatment from four replicate experiments. There were no significant differences ($P > 0.05$) between treatments within bacteria categories.

monella and *Lactobacillus* spp., and *C. perfringens* at the lowest level. The goal was to contaminate blades with enough bacteria to be able to measure reductions. Treatments applied to knives seldom were capable of complete elimination of inocula. Based on a survey of implements in factory environments, the inoculation levels were also somewhat realistic. In that study, swab samples taken on blades, sharpening steels, and hooks at a beef packing plant showed wide variability in counts of aerobes (<1 to >6 log CFU per item or 100 cm^2) for equipment used on the slaughtering floor, and coliforms were between 2 and 7 log units less than the number of aerobes *(9).* The log total number of *E. coli* recovered from the same equipment was between 0 and 3 log less than was the number of coliforms.

Simulation of the brief dip treatments of contaminated knives in HW suggests that limited efficacy is achieved on production utensils and equipment with current practices. However, replacement of HW with sanitizers did not sufficiently enhance bacterial reductions achieved by 1-s immersions. The data clearly indicate that 15-s immersion times result in greater reductions of bacteria (1.5 to 3 log) as compared with reductions achieved with 1 s (ca. 1 log). Of the sanitizers tested, it appears that acid QAC is the most suitable alternative to HW for this application, followed by neutral QAC and then PAA. Mosteller and Bishop *(13)* proposed that a 3-log reduction in populations of surface-adherent cells is a reasonable goal for effective sanitation. Their investigations demonstrated that use of 43.3 to 54.4°C (110 to 130°F) hot water, followed by 150 to 200 ppm QAC was capable of achieving >3.0-log reductions in aerobic microorganisms on food contact surfaces.

Because manual scrubbing during washing with sanitizers has been shown to reduce the recovery rate of *E. coli* O157:H7 from stainless steel following meat grinding *(5),* the effect of scrubbing was also evaluated in the present study. Significantly greater reduction of *E. coli* O157:H7 and *Salmonella* Typhimurium DT104 by 15-s HW scrubbing versus acid QAC with scrubbing could be due to physical removal of cooked meat residues that was otherwise not achieved by 15 s HW without scrubbing. It is possible that fats on knives were loosened upon immersion and scrubbing, which limited the thermoprotective effect of fats. The reduction of *C. perfringens* vegetative cells on knives was not significantly different between HW and acid QAC with scrubbing. Although spores were included in the inoculum, the knife sampling method did not include a heat shock component, and therefore the fate of *C. perfringens* spores is unknown.

TABLE 3. *Log reductions of pathogenic and spoilage bacteria on contaminated knife blades achieved by various 15-s immersion treatments*

Treatment[a]	Mean log reductions of bacteria ± SD[b]				
	Aerobic mesophiles	*Escherichia coli* O157:H7	*Salmonella* Typhimurium DT104	*Clostridium perfringens*	*Lactobacillus* spp.
82.2°C/180°F, hot water (HW)	3.13 ± 0.49 A	3.02 ± 0.99 A	2.39 ± 0.59 A	2.03 ± 0.34 A	2.04 ± 0.58 A
48.9°C/120°F, warm water (WW)	1.14 ± 0.52 B	0.78 ± 0.30 C	0.25 ± 1.03 C	0.80 ± 0.65 AB	1.05 ± 0.09 B
440 ppm SS 4 quat (QAC)	2.16 ± 1.17 AB	2.38 ± 1.46 AB	1.49 ± 1.77 AB	1.50 ± 0.60 A	2.17 ± 0.97 A
440 ppm SS 4 acid quat (acid QAC)	2.89 ± 1.16 A	3.04 ± 1.21 A	1.66 ± 1.54 AB	1.18 ± 1.03 A	2.46 ± 0.35 A
165 ppm peracetic acid and 700 ppm H_2O_2 (PAA)	1.88 ± 0.65 AB	1.52 ± 1.01 BC	1.34 ± 1.40 AB	1.41 ± 0.94 A	2.23 ± 0.90 A

[a] Sanitizing treatments consisted of a 15-s dip of the entire blade into HW or sanitizers. Sanitizers were tested at 48.9°C (120°F) at the highest concentrations approved for nonrinsed treatment of food contact surfaces.

[b] Log reductions represent mean differences between log counts on various agar media before and after treatment from three replicate experiments. Values within columns followed by different letters are significantly different ($P < 0.05$).

TABLE 4. *Log reductions of pathogenic and spoilage bacteria on contaminated knife blades achieved by 15-s immersion with scrubbing treatments*

Treatment[a]	Mean log reductions of bacteria ± SD[b]				
	Aerobic mesophiles	*Escherichia coli* O157:H7	*Salmonella* Typhimurium DT104	*Clostridium perfringens*	*Lactobacillus* spp.
82.2°C/180°F, hot water (HW)	2.92 ± 0.49 A	2.91 ± 0.48 A	2.25 ± 0.51 A	1.51 ± 0.37 A	2.53 ± 0.81 A
400 ppm SS 4 acid quat (acid QAC)	1.70 ± 0.57 B	1.70 ± 0.51 B	1.71 ± 0.71 B	1.44 ± 0.21 A	1.68 ± 0.61 A

[a] Sanitizing treatments consisted of a 15-s dip of the entire blade between two heavy bristled brushes into HW or sanitizer. Sanitizer was tested at 48.9°C (120°F) at the highest concentrations approved for nonrinsed treatment of food contact surfaces.

[b] Log reductions represent mean differences between log counts on various agar media before and after treatment from three replicate experiments. Values within columns followed by different letters are significantly different ($P < 0.05$).

Other researchers have investigated log reductions on meat cutting implements. When sharpening steels were treated with 83 ± 2°C water for 15 s, the numbers of aerobes recovered was 4 log units less than the number recovered from untreated steels *(9).* Treatment of steels with HW for 60 s resulted in aerobes and coliforms being recovered at numbers that were 1 and 2 log units less, respectively, than numbers recovered from steels treated for 15 s. However, even treatment of steels for 120 s did not completely eradicate *E. coli* from the steels.

Husband and McPhail *(10)* concluded that water at a nozzle temperature of 120°F (48.9°C) was as effective as water was at a nozzle temperature of 180°F (82.2°C) in reducing bacterial numbers on flat unclean and unsanitized surfaces. This was the primary basis of our selection of 48.9°C as the standard temperature in which sanitizing solutions were made and used. However, practicality also influenced the choice to use 48.9°C as a sanitizer temperature. At this temperature, it is expected that meat residues would not be cooked onto surfaces. Also, the use of this temperature for sanitizer vessels in plants would greatly reduce condensation on overhead surfaces.

QAC is an efficacious and approved sanitizer for food-processing equipment with a long history of successful use. QACs are approved in the United States for use on food-processing equipment and utensils and other food contact articles up to a level of 200 ppm when adequate draining is allowed prior to contact with food *(23).* The so-called fifth-generation QACs, also known as four-chain QACs, are permitted at up to 400 ppm. The QAC sanitizers used in the present study were of the latter type. Within 30 s, both 100 and 200 ppm QAC caused a 5-log reduction of *Listeria monocytogenes* cells subjected to the Germicidal and Detergent Sanitizer Test of the AOAC *(12).* Cold temperatures, such as those encountered in food-processing environments, do not substantially diminish efficacy of QAC. Using standard bacterial suspension tests set forth by the British Standards Institution, Taylor et al. *(21)* demonstrated that six different proprietary QACs passed at their recommended at-use concentration under clean and dirty conditions against *E. coli* O157:H7. Five of the six QACs passed under clean and dirty conditions when evaluated against *Pseudomonas aeruginosa.* Using the AOAC-approved sanitizer test, Lopes *(12)* showed that QAC was effective against *L. monocytogenes* and *Salmonella* Typhimurium at 100 and 200 ppm. QAC has also been shown to effectively remove microorganisms from surfaces, including stainless steel. Populations of *Staphylococcus aureus* attached to mechanically polished steel, abraded mechanically polished steel, electropolished stainless steel, and abraded electropolished stainless steel were reduced by more than 1,000-fold after treatment by submerging the steel in QAC or wiping with QAC-saturated sponges *(6).* Neutral or acid QAC at 200 ppm has been demonstrated to remove 4.6 log CFU of attached *L. monocytogenes* per cm^2 of etched stainless steel, and treatment of etched stainless steel with two QACs was just as effective as was 82.2° (180°F) water and more effective than were chlorine and iodophor *(11).*

The data presented here suggest that brief dip treatments of contaminated knives, such as those documented in pork slaughter plants, have limited efficacy. It has also been shown that longer immersion time causes greater reductions. The log reductions caused by 15-s immersions should be accompanied by scrubbing if 82.2°C water is used, but scrubbing did not seem to enhance effectiveness of acid QAC. Ideally, either HW or sanitizer treatment of contaminated knives should be preceded by a cleaning step with detergent. However, in view of the reality of high-speed slaughter conditions, QAC is a suitable alternative to HW in this application.

ACKNOWLEDGMENTS

The authors thank Nathan O. Moore and Robert Moon for their technical assistance, and Godfrey Tool & Die for knife measurements.

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