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Review

New and Established Carcass Decontamination Procedures Commonly Used in the Beef-Processing Industry†

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ABSTRACT

The fate of *Escherichia coli* O157:H7 and salmonellae as well as other potentially pathogenic bacteria resulting from fecal and other sources of contamination on red meat carcasses is a major concern. The development and validation of various decontamination procedures for red meat carcasses is not a new research area. However, recent morbidity and mortality attributable to the presence of *E. coli* O157:H7 in ground beef has heightened the awareness of and rekindled a sense of urgency for this research. Over the last few years various intervention processes have been developed and are being used to decontaminate red meat carcasses. Some of these processes include carcass rinses with antimicrobial compounds, steam, vacuum, and hot water. An overview of the results of several recent investigations demonstrating the effectiveness of these decontamination methods is presented.

Key words: Steam vacuum, moist-heat interventions, beef-carcass decontamination, organic acids, carcass washes

The general hygiene of animal carcasses has long been a concern to the meat-processing industry. However, recent fatal cases of disease caused by food-borne *Escherichia coli* O157:H7 and the implementation of new U.S. Department of Agriculture inspection regulations involving hazard analysis critical control points (HACCP) systems and pathogen reduction rules have intensified these concerns *(8)*. Consequently, carcass-decontamination procedures that will further minimize the risk of bacterial pathogens on meat products from contaminated raw carcasses are being more widely investigated and utilized by the slaughter industry.

Since a beef carcass is essentially sterile immediately after hide removal, subsequent continuous hygiene is the most effective pathogen-intervention strategy available. Consequently, the beef-processing industry makes a concerted effort to accomplish this intervention, and as a result the vast majority of carcass surfaces remain intrinsically clean. However, when carcass contamination does occur, the action that must be taken has been defined by the guidelines established by the U.S. Department of Agriculture Food Safety and Inspection Service (FSIS) *(23)*. Currently, FSIS requires that feces or ingesta of <1 in. (2.54 cm) in greatest dimension be either knife trimmed or steam vacuumed. Any feces or ingesta of >1 in., open abscesses, septic bruises, parasites or parasitic lesions, and lactating udders must be completely removed by knife trimming.

It is no surprise that knife trimming as a means of bacterial decontamination of beef carcasses has been shown to be effective in several studies *(24, 27, 38, 39)*. However, it must be remembered the majority of these studies employed highly trained personnel, utilizing good aseptic trimming techniques that are not typically seen in a slaughter facility *(38)*. It is likely that the results observed during these studies would not be repeatable by the typical employees involved with slaughter-plant knife trimming *(39)*. The investigators who have studied the effects of knife trimming recognize this shortcoming and generally conclude that it should be followed by a more encompassing carcass-decontamination intervention *(38, 39)*.

There are several acceptable interventions for reducing carcass contamination approved by FSIS that can be used without prior agency approval *(23)*. They are (i) steam-vacuum systems that utilize steam only, or water and steam; (ii) preevisceration rinse systems consisting of a water rinse and a second rinse with an organic acid solution; (iii) chlorinated water washes of 20 to 50 ppm; (iv) food-grade organic acid sprays of 1.5 to 2.5%; (v) food-grade trisodium phosphate sprays of 8 to 12% at 32 to 44°C and not to exceed 30 s; (vi) hot-water sprays at >74°C for 10 s; and (vii) steam pasteurization systems. Water and antimicrobial washes have been used by the beef-processing industry for many years, thus being the subject of many studies and the focus of

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several extensive reviews *(16, 41, 43)*. The present article will briefly discuss some of the more recent studies investigating water and antimicrobial washes, but will focus on the newer techniques of steam vacuum, hot water, and steam pasteurization.

STEAM-VACUUM SYSTEMS

The original steam vacuum was designed to take advantage of both hot water and steam, in combination with a physical removal of bacteria and contamination via vacuum (Vac-San®, Kentmaster Mfg., Monrovia, CA). Since that time, steam-only systems have also been designed and are in use in beef-processing plants.

Using the Vac-San® system, researchers determined that this type of sanitizing equipment effectively reduced fecal mesophilic aerobic bacteria, nonspecific strains of *E. coli*, and *E. coli* O157:H7 from carcass surfaces *(18, 19, 21)*. On beef-carcass tissue contaminated with bovine feces resulting in a 6-log CFU/cm^2 mesophilic aerobic bacteria inoculation, a residual range of 2.3 to 4.0 log CFU of mesophilic aerobic bacteria per cm^2 after treatment was observed. All but one of the short plates inoculated and then treated with the steam vacuum had below 3.6 log CFU/cm^2. Coliforms at initial levels of 5 log CFU/cm^2 were reduced to 1.0 log CFU/cm^2. *E. coli* viable counts of 4.8 log CFU/cm^2 were reduced to 0.8 log CFU/cm^2.

High initial inoculation levels of 7.6 log CFU of *E. coli* O157:H7 per cm^2 in a fecal menstruum on beef-carcass short plates were reduced by 5.5 log CFU/cm^2 after steam vacuuming *(18)*. Phebus et al. *(36)* observed similar residual *E. coli* O157:H7 (1.8 log CFU/cm^2) when using the Vac-San® system to remove the bacteria present in a fecal inoculum on beef-carcass tissue. In this study *E. coli* O157:H7 was reduced by 3.5 log CFU/cm^2 when using a fecal inoculum containing about 2 log fewer bacteria than those in the study by Dorsa et al. *(18)*. Phebus et al. *(36)* also determined that the steam vacuum was equally effective for removal of *Salmonella typhimurium* and *Listeria monocytogenes* cells.

Phebus et al. *(36)* noted that the steam-vacuum system resulted in greater variation of reduction levels than other moist-heat interventions tested. They speculated that this variation might be attributed to repeated passes of the nozzle over the sampled surface (25 by 12 cm) of contaminated beef which possibly embedded bacteria, therefore making them more difficult to remove by the steam-vacuuming system. Since the size of the inoculated area exceeded the width of the nozzle head during this study, this assertion seems plausible. The authors noted that the area on which FSIS allows the system to be used (<2.54-cm diameter) would probably reduce the embedding effect observed when using the system on a much larger area.

During studies with the steam vacuum *(18, 19, 21, 36)* some bleaching of the carcass surface was observed immediately posttreatment. However, after 24 h in a 4°C cooler, no color difference was noted when untreated and treated carcasses were visually compared side by side.

Resulting microbial ecology

At present, only one study has been conducted to determine the ability of a steam-vacuum system to control specific pathogens on beef-carcass surface tissue during simulated commercial storage for up to 21 days *(19)*. The steam vacuum actualized significant ($P < 0.05$) initial reductions in aerobic plate count (APC), *Listeria innocua*, and lactic acid bacteria numbers of 1.6, 2.0, and 2.0 log CFU/cm^2, respectively. However, the growth of aerobic bacteria, *L. innocua*, and lactic acid bacteria began within 2 days of refrigerated storage and reached 7 log CFU/cm^2 by 7 days. Growth of these three populations continued for the duration of the study and was equivalent to that of untreated control by day 21 *(19)*.

The population curves observed for *E. coli* O157:H7 were very different than for other bacterial groups observed during the study. *E. coli* O157:H7 populations present at 5.4 log CFU/cm^2 were reduced by 2.1 log CFU/cm^2 after application of the steam vacuum *(19)*, but after 2 days of aerobic storage at 5°C, a 1.2-log CFU/cm^2 increase in viable counts was observed. No significant growth was observed for subsequent days through 21 days, and treated carcasses had 1.4 log CFU/cm^2 fewer *E. coli* O157:H7 than untreated carcasses at 21 days.

Vegetative cells of *Clostridium sporogenes* were initially reduced by 2.1 log CFU/cm^2 on beef carcass tissue treated with steam vacuuming *(19)*. *C. sporogenes* populations continued to decrease over time and were 4.4 log CFU/cm^2 lower after 21 days than the original level of approximately 6.0 log CFU/cm^2. Li et al. *(31)* observed similar behavior over a 14-day period for *C. sporogenes* spores in heat-treated deboned turkey meat stored at 4°C. During the initial 2-day storage period, the beef surface allowed exponential growth of lactic acid bacteria, with a concomitant drop in surface pH and an increase in lactic acid concentrations in samples. Lower pH and higher lactic acid concentrations of samples after vacuum packaging probably affected the survival of remaining *C. sporogenes* vegetative cells, as has been observed for other *Clostridium* spp. *(46)*. After day 7, surviving *C. sporogenes* populations remained constant for the duration of the study.

Prior to the approval of the use of a steam-vacuuming system, the FSIS zero-tolerance policy for the presence of fecal contamination required removal of all visible feces by knife trimming. Allowing use of the steam-vacuum technology on slaughter lines has reduced the amount of knife trimming required to meet the zero-tolerance policy. In addition, it appears the use of the steam vacuum results in an improvement of the microbial constitution of beef carcasses that in the case of *E. coli* O157:H7, for example, is maintained for up to 21 days while the beef is stored under refrigeration.

In-plant use of the steam vacuum

On the basis of the studies conducted at the Roman L. Hruska U.S. Meat Animal Research Center in Clay Center, Nebraska *(18, 21)*, FSIS allowed in-plant testing of the steam vacuum designed to collect additional data to determine its efficacy under industrial use. In-plant data demon-

strated that a steam-vacuuming system was capable of consistently reducing bacterial populations from contaminated areas of less than 1 in. more effectively than knife trimming. For example, data from two typical slaughter plants (processing ca. 2,500 head per day) demonstrated that visibly contaminated areas of beef carcasses decontaminated by using the steam-vacuuming systems averaged 0.82 and 0.72 log CFU fewer residual aerobic bacteria per cm^2 than those decontaminated by knife trimming. The in-plant studies demonstrated that a commercial steam-vacuum system could consistently outperform knife trimming for the removal of bacterial contamination on beef carcasses being processed in commercial facilities.

SPRAY-WASHING SYSTEMS

In general, water washing with ambient or warm water has been found to remove ca. 1 log CFU of aerobic bacteria per cm^2 *(41)*. The effectiveness of wash technology is constantly being improved, typically through the addition of antimicrobial agents or the increase of water temperature.

Antimicrobial compounds

The addition of chlorine to water washes has been investigated and reviewed *(16, 40)*. Most researchers conclude that the incorporation of chlorine into water washes has little or no additional advantage over that seen with water-only washes, possibly a result of the high organic load present on the surface of a beef carcass *(9, 12, 28, 32, 45)*.

The effectiveness of organic acids and trisodium phosphate (TSP) on the inactivation of pathogenic and nonpathogenic bacteria associated with beef has been extensively studied and is the subject of several review articles *(2, 6, 16, 26, 30, 41, 43, 44, 47)*. It is worth noting that this large body of work has incorporated an equally large number of experimental parameters. Unfortunately, only a few of these studies used application methods that could be considered representative of the actual beef-carcass surface *(11, 20, 25, 27, 29, 37)*, since the bulk of studies conducted have used cut beef surfaces (i.e., beef cores). Another problem has been that the applications typically used for these studies (i.e., dipping, or spraying with hand-held pump sprayers that produce no pressure during application) have not been representative of industrial application methods. The beef industry presently applies acid sprays at 1.4 bar (20 lb/in^2) to a vertically hanging carcass after subjecting the carcass to a high-pressure water spray of 8.6 to 27.6 bar (125 to 400 lb/in^2). Consequently, the literature offers some conflicting results regarding the efficacy of organic acid sprays in a slaughter setting to reduce numbers of pathogenic bacteria such as *E. coli* O157:H7 on beef-carcass surfaces. Additionally, only a few efforts have been made to determine the fate of specific bacterial types on beef-carcass surfaces after the use of organic acid treatments and during subsequent refrigerated storage *(20, 29, 37)*.

Several recent studies have attempted to simulate inoculation and antimicrobial application procedures that are usable in a commercial setting. Reductions of *E. coli* O157:H7 below minimum detectable levels of 0.5 log CFU/cm^2 with initial inoculation levels of 4 and 5 log CFU/cm^2 *(20, 26)* were observed when various organic acids were applied. Dorsa et al. *(20)* also observed that TSP was capable of reducing *E. coli* O157:H7 to below detectable levels.

Resulting microbial ecology

Applications of 3% acetic acid solution to beef-carcass surface tissue yielded no better initial reductions of *E. coli* O157:H7 than water washes *(20)*, a result similar to observations made in other studies *(11, 27)*. However, growth suppression of *E. coli* O157:H7, *L. innocua*, *C. sporogenes*, and aerobic bacteria for a 21-day refrigerated storage period was significantly greater ($P < 0.05$) on beef-carcass tissue when lactic acid, acetic acid, or TSP was applied, with the exception of *L. innocua*, which exhibited growth after TSP treatments. *L. monocytogenes* has been shown to be more resistant to the effects of TSP than *E. coli* O157:H7, *Salmonella typhimurium*, and *Campylobacter jejuni* *(17, 43)*. Also TSP, to a lesser extent than any of the organic acid treatments in that study, inhibited but did not eliminate the growth of aerobic mesophilic bacteria. Kim and Slavik *(30)* also noted that TSP is effective for reducing the numbers of bacteria on beef surfaces.

Prasai et al. *(37)* and Kenney et al. *(29)* observed that the mean APCs of acid-treated carcasses were significantly ($P < 0.05$) lower than those of the control carcasses after 72 h of refrigerated storage. Anderson and Marshall *(3)* found that increasing the application temperature of acetic acid increases its ability to reduce *E. coli* on meat. However, Cutter et al. *(10)* demonstrated that when 2% (vol/vol) acetic acid was delivered through a commercial spray system using application temperatures ranging from 30 to 70°C, the residual populations of *E. coli* O157:H7 from a fecal inoculum were not different between acid treatments at any temperature. Ahamad and Marth *(1)* found that both lactic acid and acetic acid in concentrations as low as 0.1%, when incorporated into tryptose broth, inhibited the growth of *L. monocytogenes* and that the degree of inhibition increased as the temperature of incubation decreased. This effect is also supported by El-Khateib et al. *(22)*, who found that 2% lactic acid on meat surfaces had both an immediate and delayed listericidal action during 48 h of refrigerated storage. It appears that the combination of inoculation menstruum, acid temperature, volume, and application method, along with beef-tissue surface type, may play an important role in the antibacterial effectiveness of organic acid spray washes.

The large variations in the results between studies from different laboratories and the differences in techniques used in the laboratory and in the industry in applying organic acids and/or antimicrobial compounds indicate the inappropriateness of extrapolating laboratory results to the processing line. However, the studies that have most closely simulated common industrial application parameters indicate that the use of various antimicrobial compounds in commercial washes generally improves microbial quality and, potentially, the safety of the product. It should be noted that until the effects of posttreatment cross-contamination are studied, the efficacy of antimicrobial spray washes on beef carcasses will not be fully recognized.

Hot water

Decontamination of red meat carcasses using hot-water washes (70 to 96°C) has shown promise as an effective bacterial intervention method *(5, 14, 21, 25, 34, 42)*. In these studies, hot water (>70°C) was determined to be superior to water at ambient temperature for reducing general bacterial populations, including *E. coli* and salmonellae from beef or lamb carcasses; also, it did not permanently affect carcass appearance.

Patterson *(34)* showed that a hot-water and steam wash, supplied through a mixer device (80 to 96°C) for 2 min, reduced naturally occurring aerobic bacteria on beef carcasses (populations > 4 log CFU/cm^2) by less than 1 log CFU/cm^2. Subsequent studies by Barkate et al. *(5)* showed that hot-water washes of 95°C applied to beef carcasses immediately after processing reduced naturally occurring aerobic bacteria by 1.3 log CFU/cm^2. Carcass-surface temperature achieved during their study was 82°C. Davey and Smith *(14)* observed 2.2-log CFU/cm^2 reductions of *E. coli* populations that were initially present on inoculated beef carcasses at about 6.8 log CFU/cm^2 accomplished by cascading water at 83.5°C down for 10 s. By submersion in water at 80°C for 10 s, Smith and Graham *(42)* were able to achieve an average of 3.3-log CFU/cm^2 reductions of 10^6 cells of *E. coli* per cm^2 inoculated onto sheep-carcass surfaces. In the same study, populations of naturally occurring coliforms present initially at about 100 cells per cm^2 were sometimes reduced to nondetectable levels (<1 cell per cm^2), and aerobic mesophilic bacteria initially averaging 3.9 log cells per cm^2 were reduced by 1.5 log cells/cm^2.

Gorman et al. *(25)* observed that the microbial loads on beef-brisket adipose tissue inoculated with bovine feces containing 6.7 and 6.3 log CFU of aerobic bacteria and *E. coli* per cm^2, respectively, were reduced by 3.4 and 3.0 log CFU/cm^2, respectively, after the adipose tissue received a water wash at 74°C followed by a 16°C water wash. When the wash temperature sequence was reversed (16°C followed by 74°C), reductions of 3.1 and 2.6 log CFU/cm^2 were observed for aerobic bacteria of fecal origin and *E. coli,* respectively. Dorsa et al. *(21),* using a commercial carcass washer to apply a hot-water (72°C) low-pressure (20 psi) wash in combination with a high-pressure (125 lb/in^2) warm-water (30°C) wash, observed reductions on beef surface tissue of 2.7, 3.3, and 3.4 log CFU/cm^2 for APC, coliforms, and *E. coli* populations, respectively. It was also observed that a single hot-water spray wash at 82°C was capable of reducing bacterial populations of 6 log CFU/cm^2 by as much as 4.0 log CFU/cm^2 on lamb carcasses. The initial contamination levels (4 and 6 log CFU/cm^2) had little effect on final average bacterial levels (2.7 to 3.3 log CFU/cm^2). However, uninoculated carcasses with initial bacterial populations of 2.5 log CFU/cm^2 experienced a 1.5-log CFU/cm^2 reduction. It was speculated that hydration of a carcass before and during interventions afforded some protection to bacteria, perhaps due to collagen swelling and the presence of a water film. It has been demonstrated by using confocal microscopy on inoculated beef surfaces that both gram-positive and -negative bacteria readily attach to collagen and elastin fibers *(40)*.

Resulting microbial ecology

The majority of studies evaluating the efficacy of using hot water to decontaminate beef have only observed initial reductions or those detected after a very short refrigeration period. However, in experiments where carcass surface tissue was treated with a hot-water wash, allowed to chill aerobically at 5°C for 48 h, and then cut and vacuum packaged for 21 days of storage at 5°C, the APCs indicated when compared to APCs on untreated beef tissue that hot-water washes as a comprehensive antimicrobial treatment are of little value *(21)*. The growth of *L. innocua* observed during this study also suggested that the use of hot-water washes to eliminate other *Listeria* spp. might not be effective.

E. coli O157:H7 populations of 5.3 log CFU/cm^2 treated with hot-water washes were initially reduced by 2.6 log CFU/cm^2. After 2 days of aerobic storage at 5°C, *E. coli* O157:H7 achieved a 1.4-log CFU/cm^2 increase in population; however, after this initial 2-day period no significant growth was observed for 21 days. The final population of 4.6 log CFU/cm^2 was lower than the original inoculated level of 5.3 log CFU/cm^2 and considerably less than the final population of the untreated controls (6.8 log CFU/cm^2). These results indicate hot-water washes offer an additional long-term degree of safety to beef that might be contaminated with *E. coli* O157:H7 via feces during carcass processing.

STEAM PASTEURIZATION

Several studies have been conducted to determine the efficacy of using steam as a decontaminant on a variety of meat surfaces *(4, 7, 13, 15)*. An early study by Carpenter *(7)* determined that while steam was very effective at eliminating *Salmonella enteriditis* from pork carcasses, it damaged the external skin surface. Also, Anderson et al. *(4)* determined that the use of steam applied to frozen and thawed beef tissue was ineffective as a decontaminant. These studies may have contributed to an initial lack of interest in steam as a decontaminant of meat surfaces for some time.

Recently published data has led to a resurgence of interest in using steam on meat surfaces. Cygnarowicz-Provost et al. *(13)* observed a 4-log CFU/cm^2 reduction of *Listeria innocua* populations when steam was applied to beef frankfurters in a steam chamber. In this work a small-diameter-tube chamber was equipped with thermocouples placed in such a manner as to touch the surface of the beef frankfurter during treatment. A valved, vacuum-pump system was used to evacuate the chamber for 15 s, to then rapidly fill the chamber with steam, and then to evacuate the steam for an additional 10 s. The authors state that the steam was maintained at a set pressure for the desired treatment times (5, 10, 15, 30, and 40 s); unfortunately, the pressure was not reported. Dorsa et al. *(21)* compared a hot-water wash at 82.2°C to steam delivered through a closed cabinet on lamb carcasses. The steam treatment consisted of a water wash (at 15.6, 54.4, or 82.2°C and 75 lb/in^2) followed by removal of surface water by an air-blowing system, a closed-cabinet steam treatment at 1.5

in. of water, and a final cool-water rinse (15.6°C). It was concluded that moist-heat interventions were effective for reducing aerobic bacterial populations, *E. coli,* and coliforms on carcasses, regardless of the application method.

The most comprehensive studies to date aimed at determining the ability of steam to decontaminate beef surface tissue have been conducted by Nutsch et al. *(33)* and Phebus et al. *(35, 36).* Phebus et al. *(36)* conducted decontamination studies on surface tissue of freshly slaughtered beef in a steam chamber consisting of two internal compartments separated by a removable barrier. One compartment was used as a steam reservoir and the other held the beef-surface-tissue sample to be treated. The sample was subjected to the pressurized steam treatment (0.25 in. of water) by removing the barrier; then the chamber was opened after a 5-, 10-, or 15-s exposure time. The samples were rapidly cooled using a 20-s, 1°C water spray. Using this chamber, reductions in *E. coli* O157:H7, *Salmonella typhimurium,* and *L. monocytogenes* populations of 3.5, 3.7, and 3.4 log CFU/cm^2 with initial inoculations of 5.0, 5.2, and 5.4 log CFU/cm^2, respectively, were observed. They concluded that steam pasteurization can be an effective intervention in an overall system of pathogen reduction on surface tissue of freshly slaughtered beef and that its greatest effectiveness is achieved when used in combination with other decontamination treatments.

In-plant use of steam pasteurization

The use of a recently developed, commercially available, patented *(48)* steam-pasteurization chamber (Frigoscandia Food Processing Systems, Inc., Bellevue, WA, and Cargill Inc., Minneapolis, MN) was studied in a processing facility *(33).* This steam-pasteurization process consists of three distinct phases. The first phase utilizes ambient-air blowers to create an air velocity of 6,500 ft/min (1,981.2 m/min) for removal of excess water from the beef carcass surface. The second and third phases utilize a 37 by 4 by 11 ft (ca. 11.3 by 1.2 by 3.4 m) chamber in which beef carcasses are sealed in a moving chamber into which saturated steam is injected for 6 to 8 s, followed by the opening of the steam chamber, and a 10-s water wash using 44°C water at 40 psi.

Nutsch et al. *(33)* determined that initial mean APCs of 2.1 and 2.2 log CFU/cm^2 were reduced by >1.0 and 0.7 log CFU/cm^2 when beef carcasses were exposed to steam for 8 and 6 s, respectively. They also determined that the low initial populations (<1 log CFU/cm^2) of *E. coli,* total coliforms, and other species of *Enterobacteriaceae* present on the carcass surfaces were immediately reduced, in many cases, to undetectable levels. They concluded this type of steam technology could be successfully used in a beef-slaughter environment and would likely provide a microbiologically safer carcass at the end of the slaughter process.

SUMMARY

The slaughter industry uses good manufacturing practices (GMPs) when processing beef carcasses and as a result, the major portion of a carcass surface remains intrinsically clean during this process. However, unavoidable and inadvertent contamination of carcasses occurs despite GMPs, thus necessitating the use of effective antimicrobial intervention strategies. The integration of established interventions, such as knife trimming and various antimicrobial washes, with the recently developed interventions of steam vacuuming, hot water washes, and steam pasteurization will improve the microbial safety of beef carcasses immediately postslaughter. However, it is important to remember that this food product is not utilized by the consumer until some time after this point in the process. Consequently, it is important that future studies be designed with the intention of determining the long-range food-safety advantages of these interventions by monitoring the growth of bacteria of interest and pathogens past the point of initial reductions during extended storage. Additionally, the effects of post-slaughter-process contamination with pathogens should also be determined.

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