Salmonella Interventions for Beef

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Introduction

Salmonellae are ubiquitous gram-negative bacteria, generally originating from the colonized digestive tracts of birds, reptiles, and mammals (Bacon and Sofos, 2003). Salmonellosis, the illness associated with serovars of the genus *Salmonella* (Varma *et al.*, 2005), usually involves gastroenteritis and enteric fever symptoms, and is in part, transmitted through contaminated food, including various beef products. Although the majority of patients experience a 4 -7 d period of diarrhea, fever, and abdominal cramping, a fraction of patients may experience extended periods of joint pain, irritated eyes and urinary tracts, and possible development of chronic arthritis symptoms. Voetsch *et al.* (2004) estimated that, based on FoodNet data, the occurrence of U.S. nontyphoidal salmonellosis in the period 1996-1999 was 1.4 million cases, and a subsequent 168,000 doctor visits per annum (1996-1999); these culture-confirmed infections, coupled with non-culture-confirmed infections, resulted in approximately 15,000 hospitalizations and 400 deaths per annum (Voetsch *et al.*, 2004). Although various statistics (Chalker *et al.*, 1988; Mead *et al.*, 1999) verify the public health risk related to *Salmonella* infections, the true incidence of salmonellosis is not known as many foodborne illness events go unreported; it is estimated that the causative agent is determined in less than one fifth of the estimated 76 million of the U. S. annual cases of foodborne illness (Mead *et al.* 1999). Various studies have determined *Salmonella* serotypes isolated from various sources in the environment, animals, food products and ill humans (Table 1) (Bacon *et al.*, 2002a; Beach *et al.*, 2002b; CDC, 2004; Schlosser *et al.*, 2000; Sorensen *et al.*, 2002). As indicated (Table 1), *Salmonella* serovars isolated from humans match those found in cattle or meat and vice versa; however, serovar predominance can vary between human, meat product, and cattle sources. This interesting observation needs further examination.

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Proceedings of the 59th American Meat Science Association Reciprocal Meat Conference *(pp. 11-24)*
June 18-21, 2006, Champaign-Urbana, Illinois
www.meatscience.org

As salmonellosis remains an important public health risk, there is a need for its control throughout the food production chain. In order to improve the microbiological quality and reduce presence of pathogens such as *Salmonella* in beef, the United States Department of Agriculture Food Safety and Inspection Service (USDA/FSIS) introduced the process management system of hazard analysis critical control point (HACCP) in meat and poultry inspection (FSIS, 1996). In addition to the concept of HACCP and the required establishment of sanitation standard operating procedures (SSOP), the new meat and poultry inspection regulation (FSIS, 1996) introduced the requirement of microbiological performance criteria as a means of HACCP verification and pathogen reduction. Established microbiological performance criteria and standards include those for *Escherichia coli* biotype I and *Salmonella* (FSIS, 1996). In order to meet these regulatory requirements and to improve the microbiological condition of meat, the industry has sought and implemented pre-harvest pathogen control strategies and carcass sanitization or decontamination interventions (Sofos, 2002; Sofos and Smith, 1998; Sofos *et al.*, 1999a; Stopforth and Sofos, 2006). In this paper we discuss sources and extent of *Salmonella* contamination of fresh beef, and the interventions applied pre- and post-harvest for its control.

Pathogen Interactions

Potential relationships, associations, correlations and interactions of microbial species found throughout the beef production chain are not well known, and therefore, presence/absence of a specific microorganism should not be used as an index or indicator of presence or absence of others, including pathogens. More specifically, although both diarrheagenic *Escherichia coli* and *Salmonella* are enteric gram-negative bacteria, of the same family, frequently recovered from similar locations under similar conditions, one cannot be used as an indicator of the other (CDC, 2006). In recent studies, in which incidence of both *Escherichia coli* O157 and *Salmonella* was examined, no trends were evident, as to the presence and/or level of one organism being indicative of the presence and/or level of the other. Small *et al.* (2002) found that while specific locations, such as lairage pen floors, gates, knock box entries, etc, were more likely to harbor pathogenic contamination such as *E. coli* O157, *Salmonella* and *Campylobacter*, no uniform trends or

Table 1. *Salmonella* serotypes commonly associated with fed, non-fed, or unspecified cattle, the environment in slaughter facilities, meat and poultry products at the retail/restaurant level, non-meat food products (including seafood) at the retail/restaurant/consumer level, and human salmonellosis cases. Additional *Salmonella* serovars implicated in cases of human salmonellosis, that have been less frequently recovered from cattle and/or beef products include: Adelaide, Albany, Anatum var. 15+, Arechaveleta, Baranquilla, Bardo, Bareilly, Blockley, Bovismorphicans, Bredeney, Cerro, Choleraesuis var. Kunzendorf, Cubana, Give var. 15+, Give var. 15+, 34+, Haardt, Hartford, Havana, Idikan, Inverness, Kiambu, Lexington, Lille, Livingstone, London, Manhattan, Meleagridis, Minnesota, Orion, Panama, Paratyphi B, Paratyphi B var. L (+) tartrate +, Pomona, Rubislaw, Saintpaul, Sandiego, Schwarzengrund, Tennessee, Uganda, Virchow, and Weltevreden.
As derived from Bacon et al., 2002a; Bangtrakulnonth et al., 2004; Beach et al., 2002b; CDC, 1995, 2002, 2006; Fedorka-Cray et al., 1998; Gupta et al., 2003; Hedberg et al., 1992; Puohiniemi et al., 1997; Rice and Purdy, 2005; Soto et al., 2001; Taylor et al., 2000; Threlfall et al., 1998, 1999; Unicomb et al., 2005; Varma et al., 2005; Vugia et al., 2001; Wells et al., 2000; Zhao S. et al., 2003, 2006; Zhao T. et al., 2002.

	Source						
	Bovine						
Serotype	Non-specific	Non-fed/ dairy	Fed	Slaughter	Meat products	Other foods	Human
Agona		X	X		X	X	X
Anatum		X	X	X	X	X	X
Berta					X	X	X
Braenderup	X				X	X	X
Brandenburg	X				X	X	X
Derby			X	X		X	X
Dublin			X		X	X	X
Enteriditis	X				X	X	X
Give		X	X		X	X	X
Hadar	X				X	X	X
Heidelberg	X			X	X	X	X
Infantitis			X		X	X	X
Javaina			X		X	X	X
Johannesburg	X				X	X	X
Kentucky		X	X	X	X	X	X
Mbandaka		X	X	X	X	X	X
Mississippi						X	X
Montevideo		X	X	X	X	X	X
Muenster		X	X	X			X
Müenchen	X				X	X	X
Newport		X		X	X	X	X
Norwich	X				X	X	X
Ohio	X				X	X	X
Oranienburg	X		X		X	X	X
Reading			X	X	X	X	X
Senftenburg		X	X		X	X	X
Stanley	X				X	X	X
Thompson	X				X	X	X
Thyphi						X	X
Thyphimurium	X	X	X	X	X	X	X
Thyphimurium var. 5-		X	X	X		X	X
I4,[5],12:1-	X				X	X	X

associations in contamination within or between species of pathogenic bacteria were observed. Barham *et al.* (2002) recovered *E. coli* O157 and *Salmonella* from 7.0% and 74.5% of cattle transport trailers prior to shipment of ten pens of feedlot cattle (n = 46 trailers). Interestingly, on sampling dates in which *Salmonella* was recovered from 75.0% or more trailers, no (0.0%) *E. coli* O157 was recovered from any trailer; *Salmonella* was recovered less frequently from cattle trailers on sampling dates (n = 3) in which *E. coli* O157:H7 was recovered (Barham *et al.*, 2002). Rivera-Betancourt *et al.* (2004) examined and compared the pathogenic contamination of two commercial packing plants, one in the northern region, and one in the southern region of the U. S. The authors found that while incidence of *E. coli* O157:H7 and *Salmonella* was higher, incidence of *Listeria monocytogenes* was lower in the southern packing plant; the opposite trend was observed at the northern packing plant (Rivera-Betancourt *et al.*, 2004). Ransom *et al.* (2002) found that while the prevalence of *E. coli* O157:H7 compared to *Salmonella* was different in fecal, hide, and beef carcass samples (36.7, 13.3, and 0.0%, vs. 70.0, 16.7, and 6.7%. respectively), the incidence of both *E. coli* O157:H7 and *Salmonella* contamination decreased as carcasses were processed. Samelis *et al.* (2001) established that the fates of inoculated *E. coli* O157:H7 and *Salmonella* and *L. monocytogenes* were considerably different in water, lactate, and acetate carcass spray-washings residues when stored at 4 or 10ºC. However, since both *E. coli* O157:H7 and *Salmonella* are pathogens associated with fecal contamination, and although each species would be expected to respond independently to antimicrobial treatments or other factors, the application of certain processes and/or products may reduce

both pathogens similarly. Thus, although data collected for one pathogen do not necessarily reflect or predict the behavior of another, such data may be indicative of the overall picture in microbial or antimicrobial activities for various types of pathogens with similar resistance and sensitivity characteristics.

Distribution and Prevalence of *Salmonella* Contamination

Field and Feedlot

Salmonella has been recovered from many environmental locations, including fed cattle pens, feed and water sources, as well as from the feces and hides of cattle (Beach *et al.*, 2002a; Nyeleti *et al.*, 2002). As *Salmonella* is an enteric pathogen and naturally colonizes the digestive tract, animal feces and other sites exposed to those feces are likely sources of contamination (Barham *et al.*, 2002). Beach *et al.* (2002a) recovered *Salmonella* from the feces of 5.0% vs. 1.0% of feedlot vs. adult beef cattle, respectively, indicating that animal age may affect incidence of *Salmonella*. Beach *et al.* (2002b) found that type of finishing program may influence pathogen shedding by pre-harvest cattle; prevalence of *Salmonella* in hide and fecal samples of feedlot vs. non-fed beef cattle was 4.0% and 37.5%, vs. 10.9% and 37.5%, respectively. Although it has been reported that the number of feedlot cattle shedding *Salmonella* may fluctuate or even decrease throughout the feeding period, the pathogen should be generally expected to be recovered from slaughter-bound cattle (Galland *et al.*, 2000). Sorensen *et al.* (2002) found that prevalence of *Salmonella* recovered from recent arrivals vs. finished feedlot cattle was 1.9% vs. 0.2%, respectively. Barkocy-Gallagher *et al.* (2003) and Rivera-Betancourt *et al.* (2004) published results indicative of the seasonal and regional impact on prevalence of *Salmonella* recovered from feces, hides, and corresponding beef carcasses; although post-transit beef cattle were the focus of this research, pre-harvest cattle may demonstrate comparable prevalence trends.

Transportation

Although it has been hypothesized that the stress associated with animal transportation may increase shedding of pathogenic organisms by animals, results of studies designed to examine this hypothesis have been conflicting. Minihan *et al.* (2003) and Nyeleti *et al.* (2000) did not observe an increase in shedding, while others reported a dramatic increase in the level of enteric pathogens associated with hides and feces following animal transportation (Barham *et al.*, 2002; Beach *et al.*, 2002a). Following a harvest-ready cattle shipment, Barham *et al.* (2002) reported an 80.9% and 25.2% increase in *Salmonella* positive hide and fecal samples, respectively. Beach *et al.* (2002a) found that the number of *Salmonella* positive hide samples escalated from 18.0% before transit, to 56.0% following transit; incidence of the pathogen in fecal samples before and after transit were not significantly different. Beach *et al.* (2002a) also found that before shipment, fewer adult beef cattle (1.0%) shed *Salmonella*, than did feedlot cattle (5.0%); however, after transit, the number of adult cattle shedding the organism (20.8%) drastically increased while the number of shedding feedlot cattle did not (3.0%), indicating that age of harvest-bound cattle may influence level of pathogen shedding. Barham *et al.* (2002) found that, in addition to transit, gender may also influence prevalence of *Salmonella* on hides and in the feces of pre-harvest cattle. Incidence rates of *Salmonella* associated with hides and feces prior to transportation were 5.0% and 10.0%, vs.1.0% and 8.0%, for steers and heifers, respectively; following transportation, prevalence of *Salmonella* in hide and fecal samples increased to 34.8% and 21.6%, vs. 54.6% and 24.3% for steers vs. heifers, respectively. While various cattle populations may or may not exhibit an increased rate of pathogen shedding due to transport, other extraneous sources of pathogen contamination, in-transit, should also be considered. Beach *et al.* (2002a) reported that, while no trailers were positive prior to cattle shipment, 38.8% of the same trailers were positive for *Salmonella* following transportation of cattle to harvest. Conversely, Barham *et al.* (2002) found that 74.5% of the trailers used to transport cattle to harvest were already positive for *Salmonella* before cattle were loaded.

Lairage

Prevalence of *Salmonella* spp. on slaughter-ready cattle hides varies significantly (6.0 to 100.0%); this variation may be attributed to disparity among sample populations and sample collection techniques (Barham *et al.*, 2002; Barkocy-Gallagher *et al.*, 2003; Beach *et al.*, 2002a; Rivera-Betancourt *et al.*, 2004; Small *et al.*, 2002). Barham *et al.* (2002) found that the likelihood of recovering *Salmonella* from harvest-ready cattle varied between four individual sample collections spread over a three week period; prevalence of positive hide and fecal samples ranged from 6.0 to 96.4% and 72.5 to 100.0%, respectively. Rivera-Betancourt *et al.* (2004) found that the prevalence of *Salmonella* associated with hides over a five month sampling period varied between and within plants. Cattle hides at a commercial packing plant located in the southern U.S. exhibited peak prevalence in April (98.0%) and August (99.0%), and maintained elevated levels (87.9 to 95.0%) between peak prevalence months; cattle hides at a commercial packing facility in the northern U.S. exhibited a lower prevalence in April (26.7%), peaked in August (77.9%), and maintained an average incidence of 47.6% from May through July (Rivera-Betancourt *et al.*, 2004). Similarly, McEvoy *et al.* (2003) reported that, sampling cattle over a 12 month period, resulted in more frequent recovery of *Salmonella* between the months of August and October.

Cattle holding zones at slaughter facilities, referred to as lairages, have been presented as sources of pathogen contamination (Avery *et al.*, 2002). Small *et al.* (2002) reported an incidence of *Salmonella* in 1.1% of samples taken from lairage pens before initiation of daily production, and in 11.1% of samples collected during daily production when averaging the results of three separate beef packing facilities, which were sampled repeatedly over a two week pe-

riod. Rivera-Betancourt *et al.* (2004) reported differences in the number of lairage pens positive for *Salmonella* when comparing two commercial packing plants over a five month period; one packing plant was located in the southern region (52.0%), and one in the northern region (25.3%) of the U. S.

Plant environment

Incidence of *Salmonella* on carcasses may vary greatly among animal lots, and may be significantly affected by level of initial fecal and/or hide contamination (McEvoy *et al.*, 2003). Ransom *et al.* (2003) indicated that frequency of *E. coli* O157:H7, another enteric pathogen, on carcasses prior to evisceration, was 6.3% when pre-harvest pen floor fecal prevalence was < 20%; however, when pre-harvest pen floor fecal incidence was > 20%, more carcasses (14.3%) were positive for *E. coli* O157:H7 at pre-evisceration. Beach *et al.* (2002b) reported a *Salmonella* prevalence of 18 to 20% and 50 to 56% on hide samples from young feedlot and adult non-fed cattle, respectively. Furthermore, 19% and 54% of the associated carcass samples were positive for *Salmonella*, respectively. Additional sources of contamination or cross-contamination may be associated with the slaughter plant environment, equipment, utensils and humans. Beach *et al.* (2002a) found that 64.3% and 83.3% of knock boxes, at two different commercial processing facilities, were positive for *Salmonella*. Reid *et al.* (2002) reported a higher prevalence of *Salmonella* contamination associated with the brisket area (10.0%) of the hide, rather than the flank (8.8%) or rump (2.2%), prior to hide removal. Since during hide-removal, hides are opened at the brisket area, highly contaminated briskets should be addressed to prevent pathogen transfer onto carcasses.

The corresponding level of beef carcass contamination at steps within the slaughtering process would be difficult to determine as sequential antimicrobial interventions, referred to as multiple hurdles, are commonly applied to carcasses throughout the chain, and variation exists in programs applied by different processors (Bacon *et al.*, 2000; Leistner and Gould, 2002; Sofos and Smith, 1998). It is possible, however, to examine the distribution of *Salmonella* contamination associated with pre- and post-evisceration or chilled carcasses to which multiple hurdle programs have been applied. Reported prevalence of *Salmonella* contaminated carcasses, prior to evisceration, was 12.7 to 54.0%; prevalence of *Salmonella* contamination on carcasses, to which various industrial multiple hurdle programs had been applied, was 0.0 to 7.6 % (Bacon *et al.*, 2000; Barkocy-Gallagher *et al.*, 2003; Beach *et al.*, 2002a; Fegan *et al.*, 2004; McEvoy *et al.*, 2003; River-Betancourt *et al.*, 2004). Variability of pre- and post-eviscerated carcass contamination levels could be attributed to extraneous factors impacting fecal and hide contamination and subsequent load of pathogenic contamination associated with those vectors, as well as differences in slaughter practices, facilities and their design, slaughter speeds, and components of multiple hurdle programs applied at each slaughter facility. Hogue *et al.* (1993) investigated the possible correlation between slaughter volume of beef plants and *Salmonella* contamination of carcasses (brisket area) and ground beef. Incidence of *Salmonella* contamination was closely associated with initial animal health and increased with number of animal condemnations. Additionally, a decrease in the incidence of total aerobic counts was observed as slaughter volume increased; no correlation between *Salmonella* contamination and slaughter volume was observed. The authors suggested that the uniformity of slaughtered animals, in conjunction with specialization and degree of training of employees associated with high slaughter-volume facilities, may help maintain similar contamination levels exhibited by low slaughter-volume processors (Hogue *et al.*, 1993). At two geographically diverse beef slaughter facilities, Rivera-Betancourt *et al.* (2004) recovered *Salmonella* from slaughter facility floor drains before (4.0 and 4.0%) and during operations (13.3 and 23.0%), product contact surfaces (0.0 and 1.3%; conveyor belts), and locker room floor drains (0.0 and 10%). Pearce *et al.* (2006) examined the levels of aerosolized aerobic mesophiles and *Salmonella* in a pork slaughter facility, within the wet room (exsanguination, scalding, dehairing, and polishing stations), clean room (debunging, and evisceration stations), and carcass coolers sampled via impaction and sedimentation of air. Within 2 hr of operation commencement, aerosolized aerobic mesophiles within the wet room, clean room, and carcass coolers were 3.14, 2.66, and 2.34 log CFU/m^2, respectively; aerosolized *Salmonella* Typhimurium was detected on one of three visits at both the dehairing and evisceration stations (Pearce *et al.*, 2006). Data reported by Tutenel *et al.* (2003) indicate that 26% of apron, and 29% of knife samples, collected from harvest-floor employees over a 3-day period, were positive for *E. coli* O157; as both *Salmonella* and *E. coli* O157 are enteric pathogens, this equipment should be considered as a possible contamination route.

Products and Impact

Following chilling (24-72 h), just before fabrication, Kain *et al.* (1999) found that 0.7% and 1.7% of beef carcasses carried *Salmonella*, via sponge and excision sample collection, respectively. Kain *et al.* (1999) also found that beef subprimals originating from retail, had higher microbial counts than subprimals taken directly from the packing plant. Sorensen *et al.* (2002) collected ground beef samples from retail outlets and 1.3% of them were positive for *Salmonella* spp. Even more alarmingly, of the 208 bacterial foodborne disease outbreaks reported by the Foodborne Diseases and Diarrheal Branch in 2004, 123 (59.1%) could be traced back to *Salmonella* spp. Of those 123 *Salmonella* outbreaks, five (4%) were attributed to beef products or products containing beef; food-source was undetermined for 55 (44%) of the *Salmonella* outbreaks (CDC, 2004). Due to the potentially negative impact on consumer health and perception of beef products, when associated with *Salmonella* contamination and/or subsequent foodborne illness, it is essential to posses a clear understanding of sources of *Salmonella* contamination, as well as the efficacy of methods and interventions used to control such contamination.

Application of interventions is also necessary because of regulatory microbiological performance criteria (FSIS, 1996) and contractual microbiological specifications (Sofos, 2002; Sofos and Smith, 1998; Stopforth and Sofos, 2006).

Interventions

The most comprehensive strategy for improving the microbiological quality and safety of meat (Stopforth and Sofos, 2006) includes the application of technologies that: (i) minimize sources and reduce levels of contamination for the live animal; (ii) minimize access or transfer of cells from the animal s exterior and the slaughter environment to the carcass or meat; (iii) reduce levels of contamination that have gained access to the carcasses or meat; (iv) inactivate microbial cells on the meat; and, (v) prevent or control growth of cells which have gained access to the meat and have not been inactivated. In general, control of microbial contamination on meat products may be accomplished through pre- and post-harvest, as well as processing and foodservice interventions. Control of contamination on the animal carcass may be achieved through proper animal hide cleaning and carcass sanitization or decontamination interventions and chilling, while control at the food processing level is accomplished through thermal and non-thermal (e.g., high pressure) physical interventions, fermentation, drying, refrigeration or freezing, antimicrobial additives and packaging. In general, meat preservation is achieved through combinations of antimicrobial interventions in multiple-hurdle technology systems (Leistner and Gould, 2002). The objective is to optimize the effect of individual antimicrobial interventions in order to achieve an additive or synergistic effect that is greater than the sum of individual treatments (Stopforth and Sofos, 2006).

Ideal pre-harvest pathogen control interventions should be animal and environment friendly, while raw meat decontamination treatments should not alter the organoleptic properties of the product, leave residues, harm the environment, plant personnel or consumers, or otherwise be of legitimate concern to consumers, public health officials, regulators or legislators. In addition, they should be effective against various pathogens, economical and simple to apply, as well as capable of extending shelf-life via inhibition of spoilage organisms without masking spoilage (Corry *et al.*, 1995; Sofos and Smith, 1998). A vast array of processes and technologies have been investigated in pursuit of the ideal antimicrobial sanitization or decontamination interventions, or the most ideal sequence or combination of independently successful interventions, both pre- and post-harvest (Sofos, 2002; Stopforth and Sofos, 2006). Such interventions include the following.

Pre-harvest Interventions

As indicated, *Salmonella* is frequently recovered from the hides and feces of feedlot cattle, as well as other environmental sites such as soil, water, feed-bunks and loading chutes. Therefore, it is reasonable to seek and investigate pre-harvest antimicrobial programs for control of this pathogen (Beach *et al.*, 2002a, 2002b; Nyeleti *et al.*, 2002; Sofos, 2002; Stopforth and Sofos, 2006). In general, control of pathogen prevalence in live animals prior to arrival at slaughterhouses may be achieved through application of good animal management practices such as market classification of animals, clean housing, food, water and pest control, and transport/lairage control, or via antimicrobial interventions such as feeding of pathogen displacement agents (prebiotics, probiotics, and competitive exclusion), feed additives, antibiotic treatments, vaccine administration, and bacteriophage therapy (Sofos, 2002; Stopforth and Sofos, 2006). Overall, pre-harvest pathogen control is difficult due to many, unpredictable, and uncontrollable sources of contamination and cross-contamination. Some recent promising efforts include the potential use of chlorate (5 mM), which as reported by Anderson *et al.* (2000) reduced populations of *E. coli* 0157:H7 and *S.* Typhimurium DT104 inoculated (1×10^5 log CFU) in buffered rumen contents to below the detection level (≤ 10 CFU) within 24 (Table 2). Chlorate, which is not yet approved for commercial use, is lethal only to organisms capable of respiratory nitrate reductase expression resulting in the reduction of chlorate to bactericidal chlorite ions; *E. coli* O157:H7 and *Salmonella* express nitrate reductase, while rumen anaerobes do not and were minimally affected (Anderson *et al.*, 2000). Other approaches include use of direct-fed *Lactobacillus acidophilus* cultures (Brashears *et al.*, 2003; Younts-Dahl *et al.*, 2004),

Table 2. Pre-harvest treatments for reduction of *Salmonella* and other bacteria in the feces and/or on the hides of cattle.

Treatment	Experimental unit	Pathogen(s)	Overall reduction(s)	Comments	Reference
Sodium chlorate 5 mM (pH 6.8); 24 hr	Buffered rumen contents	*Salmonella* Typhimurium DT104, *E. coli* O157:H7	6 log CFU/ml	More effective at pH 6.8 than 5.6; did not adversely affect rumen microbes	Anderson *et al.* (2000)
Ascophyllum nodosum Tasco-14; Brown Seaweed; 2% DM basis; 14 d	Fecal samples and hide swabs	*Salmonella, E. coli* O157:H7	A 14 d feeding period did not reduce prevalence of *Salmonella* spp. detected in feces of Tasco-14 treated steers		Braden *et al.* (2004)
Dust abatement via application of retention pond water 1,400L/min; 3-6 min; Computer-controlled, high-pressure sprinkler system	Fecal samples and hide swabs	*Salmonella, E. coli* O157:H7	No difference in pathogenic populations associated with treatment vs. control feedlot steers	Pathogen levels associated with retention-pond water were not examined; high likelihood of contaminated pond water	Loneragan and Brashears (2005a)

administration of neomycin sulfate which is currently approved as a water/feed supplement for the prevention or treatment of bacterial enteritis (Loneragan and Brashears, 2005b), and use of vaccines (Potter *et al.*, 2004). It should be noted that the main target of these interventions has been *E. coli* O157:H7 and not *Salmonella*.

It is of paramount importance to ensure that methods intended to control pathogens are not in fact contributing to the problem. Loneragan and Brashears (2005a) investigated the efficacy of applying retention-pond water to feedlot pens as a form of dust control (Table 2). It was suggested that the retention-pond water may have served as a vehicle of pathogen contamination, as storm run-off from feedlot pens was the most significant contributor to the pond (Loneragan and Brashears, 2005a). While an intervention program may not be a contributor of pathogenic contamination, not all programs may be adequately effective. For example, *Ascophyllum nodosum* (TASCO-14) or chlorinated water used to control *Salmonella* and *E. coli* O157:H7 (Braden *et al.*, 2004; LeJeune *et al.*, 2004) had mixed results. It should be noted that the likelihood of recovering a pathogen may be influenced, not only by the intervention treatment, but also by environmental factors such as temperature and precipitation, and the health of animals. Additionally, level of stress due to water and/or feed starvation or transportation, may affect the pathogen load associated with a particular group of animals (Galland, 1997). Although the recommendation of employing good management or production practices at the feedlot level may seem superfluous, proper maintenance of facilities and holding areas, as well as attentiveness to animal health cannot be replaced by application of intervention technologies. For example, regular pen maintenance appears to deter inevitable pathogenic residents, and maintain them at lower levels (Smith *et al.*, 1997).

Hide decontamination

The potential of the hide to contribute to carcass contamination is a realistic concern, and therefore, attention to hide decontamination technologies is important. Modifications of typical slaughter practices have been recommended for application during slaughter of highly-contaminated cattle (Sofos, 2002). These suggestions include the separation of minimally- from highly-contaminated lots of cattle at lairage, creating some division and separation of clean and dirty operations throughout the slaughtering process, as well as better management of carcasses within highly-contaminated lots and adequate maintenance of equipment used to process them (Gill *et al.*, 1998; Hadley *et al.*, 1997; Sofos and Smith, 1998). When evaluating the performance of an antimicrobial intervention, practicality for large-scale application as a commercial intervention is an essential issue. Small *et al.* (2005) investigated the use of hide clipping, followed by singeing with a hand-held blow torch versus the use of food industry disinfectants to reduce total bacterial counts associated with cattle hides. Although the clipping and singeing treatment reduced (2.31 log CFU/cm^2) total viable counts of bacteria more effectively than 10% Betane Plus and P3-Topactive DES treatments (1.98 and 0.97 log CFU/cm^2, respectively), it would not be feasible to clip and singe all hides of animals slaughtered by an average commercial packing facility.

Table 3. Hide decontamination methods used to reduce *Salmonella* and other bacteria in the feces and/or on the hides of cattle.

Treatment	Experimental unit	Pathogen(s)	Overall reduction(s)	Reference
Hide Chemical Dehairing				
	Hides and pre-evisceration carcasses	Aerobic plate counts, *Enterobacteriaceae*, *E. coli* O157:H7	Prevalence of *E. coli* O157:H7 on dehaired vs. conventionally processed was 67% vs. 88%, respectively; *Enterobacteriaceae* and aerobic plate counts were not different between treatment and control groups	Nou *et al.* (2003)
	Hides and pre-evisceration carcasses	*Salmonella* Typhimurium	Reduced (by approximately 5.1 log CFU/cm^2) to below detectable levels	Castillo *et al.* (1998a)
Hide Washing				
Cetylpyridinium chloride 1%; 500 lb in-2, 5 cm from hide; 3 min spray, followed by 1 min spray	Hides and pre-evisceration carcasses; prior to stunning	Aerobic plate counts, *Enterobacteriaceae*, *E. coli* O157:H7	*E. coli* O157:H7 on treated vs. control hides and carcasses was 34% vs. 56%, and 35 vs. 23%, respectively; treatment also decreased *Enterobacteriaceae* and aerobic plate counts by 1.1 and 1.5, and log CFU/100cm^2, respectively	Bosilevac *et al.* (2004)
Ozonated water 15ºC; 2 ppm; 4800 kPa for 10 sec	Hides; simulated hide wash	Aerobic plate counts, *Enterobacteriaceae*, *E. coli* O157:H7	Reduced *Enterobacteriaceae* and aerobic plate counts by 3.4 and 2.1 log CFU/100 cm^2, respectively; *E. coli* O157:H7 in treatment vs. control hide samples was 31% vs. 81%, respectively	Bosilevac *et al.* (2005a)
Alkaline and Acidic electrolyzed oxidizing water 60ºC; 4800 kPa or 1700 kPa for 10 sec	Hides; simulated hide wash	Aerobic plate counts, *Enterobacteriaceae*, *E. coli* O157:H7	Reduced *Enterobacteriaceae* and aerobic plate counts by 4.3 and 3.5 log CFU/100 cm^2, respectively; *E. coli* O157:H7 in treatment vs. control hide samples was 35% vs. 82%, respectively	Bosilevac *et al.* (2005a)
Multiple antimicrobial treatments and water or acidified chlorine (ACl) rinse, ± vacuum treatment 60ºC; 200, 500 ppm ACl, pH 7.0; 1,200 lb in^{-2} for 20 sec	Hides; simulated hide wash	Aerobic plate counts, *Enterobacteriaceae*, *E. coli* O157:H7	Addition of 200 or 500 ppm acidified chlorine rinse to initial antimicrobial treatments reduced populations by an additional 1.0 to 2.0 log CFU respectively; vacuuming treated areas also reduces populations by an additional 1.0 log CFU	Bosilevac *et al.* (2005b)
L-Lactic acid (LA; 2, 4, or 6%) Acetic acid (AA; 2, 4, or 6%) Chlorine (CL; 100, 200, or 400 ppm) Ethanol (ET; 70, 80, or 90%) Oxy-Sept 333 (OS; 0.5, 2, or 4%)	Hide samples; inoculated; simulated hide wash	Rifampicin-resistant *Salmonella* Typhimurium	LA at 2, 4, and 6% reduced *S.* Typhimurium by 1.3, 3.3, and 5.1 log CFU/cm^2; AA at 2, 4, and 6% by 2.4, 3.8, and 4.8 log CFU/cm^2; ET at 70, 80, 90% by 5.2, 5.0, and 5.5 log CFU/cm^2; CL and OS did not reduce *S.* Typhimurium ≥ 1.5 log CFU/cm^2 at any concentration	Mies *et al.* (2004)

Chemical dehairing of beef carcasses (Sofos and Smith, 1998) has also shown potential as an antimicrobial intervention (Nou *et al.*, 2003). Castillo et al (1998a) reported that chemical dehairing of inoculated hide pieces reduced *S.* Typhimurium (by approximately 5.1 log CFU/cm^2) to below detectable levels (Table 3). The success of this technology at reducing bacterial levels, however, is overshadowed by the caustic agents used, and the effluent produced by these systems (Sofos and Smith, 1998; Stopforth and Sofos, 2006). Mies *et al.* (2004) examined the efficacy multiple concentrations of lactic acid (2 - 6%), acetic acid (2 - 6%), chlorine (100 - 400 ppm), or ethanol (70 - 90%) at reducing *S.* Typhimurium on cattle hides (Table 3). Inoculated hide populations (10^6 log CFU/ml) experienced reductions of ≥ 1 log when treated with ethanol (5.2 - 5.5 log CFU/cm^2), lactic acid (1.3 5.1 log CFU/cm^2), and acetic acid (2.4 4.8 log CFU/cm^2) at any concentration; 400 ppm chlorine reduced populations by 1.3 log CFU/cm^2. However, at the antimicrobial concentrations required for significant reduction, live-animal application would not be feasible from an animal welfare perspective (Mies *et al.*, 2004).

Other hide decontamination treatments found to some extent effective against various microorganisms (Table 3) include cetylpyridinium chloride (CPC) solutions, ozonated water (15ºC), and alkaline or acidified electrolyzed (60ºC) water (Bosilevac *et al.*, 2004; 2005a). Bosilevac *et al.* (2005b) investigated the efficacy multiple antimicrobial agents as hide washes, alone and in conjunction with a water or acidified chlorine rinse, with or without a final vacuuming of treated areas (Table 3). When compared to water washing only, the acidified chlorine rinse at 200 and 500 ppm reduced coliforms by an additional 1.0 and 2.0 log CFU/100cm^2, respectively, while additional vacuuming of the treated area reduced coliforms by an additional 1.0 log CFU/100cm^2 (Table 3). Location of application of hide washes, within the facility, may be problematic for pre-existing processing plants, thus, making hide washes applied to live cattle within animal holding areas more attractive. Fortunately, after hide removal, carcasses are typically

subjected to numerous decontamination interventions; therefore, total elimination of hide contamination is not obligatory.

Carcass decontamination

For obvious reasons, the majority of decontamination interventions have been focused upon beef carcasses after hide removal, before and/or after evisceration, and before chilling, and to some extent following chilling and before fabrication (Stopforth and Sofos, 2006). It is during the transitional period, of hide-on carcasses to sides of beef, that the product is initially contaminated; all interventions prior to hide removal simply reduce, without eliminating, pathogen populations associated with potential vectors. Spot decontamination methods, such as steam-vacuuming and knife trimming are widely used to remove visible contamination or systematically applied to typically contaminated areas. This type of intervention is invaluable and necessary, as it allows for the removal of visible contamination prior to carcass washing, as required by zero tolerance FSIS directives (Huffman, 2002; Sofos and Smith, 1998; Stopforth and Sofos, 2006).

Other commonly used decontamination treatments applied during slaughter and dressing include rinsing of carcasses (pre-evisceration) or carcass sides (post-evisceration) with organic acid (lactic or acetic) or other chemical solutions and/or application of thermal treatments involving hot water or steam. The efficacy of low concentrations (1.0% to 2.5%) of organic acid solution application in reducing *S.* Typhimurium found on beef carcass surfaces has been investigated (Dickson and Siragusa, 1994; Hardin *et al.*, 1995; Prasai *et al.*, 1991, 1997) (Table 4). By applying these acids at higher pressure and at an elevated temperature additional microbial reductions may be achieved (Hardin *et al.* 1995). A study conducted by Cutter and Rivera-Betancourt (2000) estimated that lactic (2%) or acetic (2%) acid reduced levels of *S.* Typhimurium DT104 populations by ≥ 2 log CFU/cm^2 (Table 4). Analogously, 2% acetic acid was shown to be capable of sublethally injuring approximately 65% of vari-

Table 4. Individual treatment information and results of carcass washes in which organic acids were utilized to reduce *Salmonella* and other bacterial populations (naturally occurring or inoculated) on the surfaces of various beef products.

Treatment	Experimental unit	Pathogen(s)	Overall reduction(s)	Comments	Reference
Acetic acid 2.0%; 35 ± 2ºC; 125 ± 2 psi spray	Beef tissue surface; inoculated/fecal slurry	*Salmonella* Typhimurium, *E. coli* O157	> 2 log CFU/cm^2	10% Sodium triphosphate was more effective than lactic or acetic acid	Cutter and Rivera-Betancourt (2000)
Acetic acid 2.0%; ambient	Beef tissue Surface; inoculated	*Salmonella* Typhimurium	Sublethal injury to 65%; 1 log after 4 h		Dickson (1992)
Acetic acid 2.0%; spray post-fabrication	Beef Steak; inoculated	*Salmonella* Typhimurium, *E. coli* O157, Total aerobes	1 log CFU/cm^2		Tinney *et al.* (1997)
Lactic acid 2.0%; 35 ± 2ºC; 125 ± 2 psi spray	Beef tissue surface; inoculated/fecal slurry	*Salmonella* Typhimurium DT104, *E. coli* O157:H7	> 2 log CFU/cm^2		Cutter and Rivera-Betancourt (2000)
Lactic acid 1.0%; 23ºC; wash Final intervention Spray- or dry chilled at 5º for up to 21 d	Beef tissue surface; inoculated	*Salmonella* Typhimurium, *E. coli* O157:H7, *L. monocytogenes* Scott A	Acid washed pathogen populations were lower than 23ºC water washed populations; no difference in pathogen populations immediately following treatment vs. after simulated carcass spray- or dry-chilling (5ºC for 3 d)		Dickson and Siragusa (1994)
Lactic acid 1.0%; 55ºC; Spray; pre- and/or post-evisceration	Beef tissue surface	*Salmonella*, *Listeria*, Total aerobes	*Salmonella* ND; >90% Total aerobes	Most effective when applied at post- or pre- + post-evisceration	Prasai *et al.* (1991)
Lactic acid 1.5%; spray Post-fabrication	Beef strip loin	*Salmonella*, *Listeria*, Total aerobes	*Salmonella* ND; *Listeria*, treatment 4%, control 28% +; Total aerobes lower on treated loins (97%) than controls	Post-storage treatment more effective than pre-storage treatment	Prasai *et al.* (1997)
Lactic acid (LA) and hot water (HW) sprays alone or in combination LA: 25; 55ºC HW: 95ºC	Hot beef carcass surfaces; inoculated	*Salmonella* Typhimurium, *E. coli* O157, Generis *E. coli, Enterobacteriaceae,* Total aerobes, Thermotolerant indicator organisms	Reductions in *S.* Typhimurium (log CFU/cm^2) via HW only(4.0), LA only (4.6), LA + HW (4.4), and HW + LA (4.5) were not affected by order of application in multiple factor treatments		Castillo *et al.* (1998c)
Carcass trimming vs. water wash (35ºC) followed by Lactic acid (LA) or Acetic acid AA) spray (2%; 55ºC; 40 psi)	Hot beef carcass surface pieces; inoculated	Rifampicin-resistant *Salmonella* Typhimurium, *E. coli* O157,	Average of individual carcass region results: trimming reduced *Salmonella* by 3.2 log CFU/cm^2; water by 2.6 log CFU/cm^2; water + LA by 4.6 log CFU/cm^2; water + AA by 4.3 log CFU/cm^2	Decontamination was significantly affected by carcass region	Hardin *et al.* (1995)

ous *S.* Typhimurium inoculum levels, followed by a residual 1 log reduction 4 hr later (Dickson, 1992) (Table 4). Due to the effectiveness of organic acid treatments in reducing *Salmonella* associated with beef carcasses in multiple investigations, the use of similar treatments for commercial application is widely practiced (Stopforth and Sofos, 2006).

The effects of several other chemical washes on the bacterial populations of beef carcass surfaces have been examined with diverse results. These chemical solutions include ordinary and modified chlorine, trisodium phosphate, hydrogen peroxide, ozone, sodium bisulfate, sodium chloride, acidified sodium chlorite, nisin, potassium sorbate, and cetylpyridinium chloride (Sofos and Smith, 1998; Stopforth and Sofos, 2006). Trisodium phosphate has been approved for use in the U. S. beef and poultry industries, and has been shown to reduce bacterial contamination and may also reduce bacterial attachment on carcass surfaces (Cabedo *et al.*, 1996; Gorman *et al.*, 1997; Sofos *et al.*, 1999b). Aqueous ozone applied on inoculated beef did not reduce populations of *S.* Typhimurium or *E. coli* O157:H7 more than multiple water washes (Castillo *et al.*, 2003).

Thermal inactivation of bacteria may have the advantage of not being accompanied by chemical solution residues; however, it lacks residual antimicrobial activity which may be present in product treated with acidic washes (Ikeda *et al.*, 2003; Koutsoumanis *et al.*, 2004). Nevertheless, the value of a hot water application to beef carcasses can not be overlooked as bacterial reductions via hot water treatments can be substantial (Graves-Delmore *et al.*, 1997; Reagan *et al.*, 1996). Castillo *et al.* (1998b), Cutter and Rivera-Betancourt (2000), and Smith (1992) investigated reductions of *Salmonella* associated with inoculated fresh beef tissue, when sprayed with hot water (72-95ºC) for 10-20 sec (Table 5). *Salmonella* populations in all studies were reduced by ≥ 2 log CFU/cm^2; level of reduction increased as water-spray temperature increased from 72ºC to 95ºC (Table 5). Hot water temperatures should be selected to induce the largest possible bacterial reductions, while minimizing negative impact on carcass quality or appearance (Sofos and Smith, 1998).

The use of steam as a thermal antimicrobial treatment has also been approved for use in the U. S. Phebus *et al.* (1997) found that application of a patented steam pasteurization treatment (92 ± 1ºC; 15 sec) reduced inoculated *Salmonella* populations (5.15 log CFU/cm^2) on freshly slaughtered beef carcass surfaces by 3.74 log CFU/cm^2. Retzlaff *et al.* (2004) investigated the use of vertical tower steam pasteurization in reducing pathogenic populations associated with inoculated beef tissue, in a simulated slaughter floor steam cabinet (Table 5). All pathogen populations were reduced by ≥ 2.0 log CFU/cm^2 at 93.3 and 98.8ºC; however, the time required to obtain these reductions exceeded recommended exposure time (6 sec) to avoid carcass discoloration defects (Gill *et al.*, 1998; Retzlaff *et al.*, 2004). A steam pasteurization exposure interval of 6 sec can reduce bacterial populations by 1-2 logs without detrimental discoloration defects (Gill *et al.*, 1998).

To ensure that only the outer surfaces of beef carcasses are treated with chemical solutions, care should be taken to address any rips or cuts created in the subcutaneous fat layer via mechanical hide removal. Simpson *et al.* (2006) found that 5% of pockets formed by such surface cuts contained accumulated decontamination fluids positive for *E. coli* O157:H7 when tested after carcass chilling and before fabrication. These fat tears may be covered with plastic film to avoid collection of fluids and/or bacteria in these sites,

Table 5. Individual treatment information and results of antimicrobial carcass treatments via thermal inactivation used to reduce *Salmonella* and other bacterial populations (naturally occurring or inoculated) on the surfaces of various beef products.

Treatment	Experimental unit	Pathogen(s)	Overall reduction(s)	Reference
Hot water 95ºC; spray	Fresh beef tissue; inoculated	*Salmonella* Typhimurium, *E. coli* O157:H7, Total aerobes, Thermotolerant indicator organisms	3.7, 3.8, 2.9, and 3.3 log CFU/cm^2, respectively; efficacy was affected by carcass surface region	Castillo *et al.* (1998b)
Hot water 80ºC; 10-20 sec spray	Fresh beef tissue; inoculated	*Salmonella, E. coli,* EPEC, *Aeromonas hydrophila, Yersinia enterocolytica, Pseudomonas fragi, Listeria monocytogenes*	> 3 log (99.9%)	Smith (1992)
Hot water 72ºC; 15 sec spray; 125 psi	Beef surface; inoculated fecal slurry	*Salmonella* Typhimurium DT104, *E. coli* O157:H7	>2 log CFU/cm^2	Cutter and Rivera-Betancourt (2000)
Multiple rapid desiccation Dry heat at 300ºC; Desiccation [10 sec], Inoculation, water wash, Desiccation [25 sec]	Beef tissue	*Salmonella* Typhimurium, *E. coli* O157:H7, *Listeria innocua,Clostridium sporogenes,* Total aerobes	> 4 log CFU	Cutter *et al.* (1997)
Steam vacuum 130ºC; 1.72 bar	Chilled beef adipose; inoculated	*Salmonella* spp.	0.5-0.7 log CFU/cm^2	Bacon *et al.* (2002c)
Vertical tower steam pasteurization 82.2, 87.8, 93.3, or 98.9ºC; 0, 3, 6, 9, 12 or 15 sec	Beef tissue; inoculated	*Salmonella* Typhimurium, *E. coli* O157:H7, *Listeria innocua*	≥2.0 log CFU/cm^2 at 93.3ºC for 15 sec; at 98.8ºC for 6-15 sec.	Retzlaff *et al.* (2004)

which could remain undetected and even result in bacterial cell selection or adaptation to stresses such as acid used in decontamination. Although the use of organic acids to reduce pathogenic bacteria on carcass surfaces is practiced widely in the U. S., concerns regarding potential selection of acid-tolerant organisms, undesirable meat quality effects, and accelerated corrosion of harvest-floor equipment, associated with use of these acids are not unwarranted (Samelis and Sofos, 2003; Sofos and Smith, 1998).

Combinations of Multiple Decontamination Treatments

It is logical that decontamination interventions could provide a greater, even synergistic, antimicrobial activity when used in combination (Bacon *et al.*, 2000; Graves-Delmore *et al.*, 1998; Sofos and Smith, 1998; Sofos *et al.*, 1999a). Bosilevac *et al.* (2005b) found that by adding an acidified chlorine rinse after a previous antimicrobial hide rinse, then vacuuming the treated hide area, bacterial populations were reduced by an additional 2.0 to 3.0 log CFU/100cm^2, above the initial reductions of the antimicrobial treatment only. Hardin *et al.* (1995) found that antimicrobial acid treatments were more effective at elevated (>55ºC) temperatures. The effect of multiple hurdles (Leistner and Gould, 2002) on the incidence of *Salmonella* was examined at eight commercial packing facilities (Bacon *et al.*, 2000). On average, prevalence of *Salmonella* was reduced from 14.7% to 1.9% following completion of individual multiple hurdle programs at each facility. Stopforth *et al.* (2005) investigated reductions of *S.* Typhimurium on inoculated beef plates when using lactic acid, sodium metasilicate, ammonium hydroxide, and alkaline or acidified oxidized water, singly or in combination. The application of two 5% lactic acid treatments, or a single hot (82ºC) application of another antimicrobial plus a single 5% lactic acid treatment were both more effective than all other single or combination treatments at reducing *S.* Typhimurium. Improved performance and/or synergy of treatment combinations may be affected by order of application. Castillo *et al.* (1998c) found that lactic acid followed by a hot-water wash was more effective than hot-water washing followed by a lactic acid treatment. However, Koutsoumanis *et al.* (2004) found that the order in which 55ºC lactic acid (LA) and 75ºC water (HW) treatments were applied did not significantly affect level of reduction of *L. monocytogenes* inoculated on fresh beef tissue; reductions of 2.68 and 2.73 log CFU/cm^2 were observed for LA-HW and HW-LA treatments, respectively.

Carcass Chilling, Fabrication and Further Handling

The last harvest-floor intervention is commonly referred to as the final intervention ; this is not necessarily accurate. Carcasses undergo further handling and may be exposed to additional contamination, cross-contamination, decontamination or pathogen elimination steps before consumption. Following dressing and decontamination, carcass sides undergo chilling before cutting and boning (Stopforth *et al.*, 2004). Characteristics of individual chilling methods and facilities can directly increase or decrease contamination or influence the generation interval of any bacteria remaining on carcass surfaces. Simpson *et al.* (2006) found that, as carcass surface temperature decreased to 4ºC within 9.33, 11.0, or 21.7 hr following slaughter, total coliform counts decreased, did not change, or increased during chilling (approximately 48 hr), respectively. The antimicrobial effects of certain harvest-floor interventions may persist throughout storage (Ikeda *et al.*, 2003). Koutsoumanis *et al.* (2004) found that when acid was applied to beef tissue last, it reduced rate of microbial growth during subsequent product storage more than when acidic was followed by hot water spraying. Özdemir *et al.* (2006) found that the application of a 1% or 2% lactic acid spray alone or followed by a hot water (82ºC) treatment reduced initial populations of *S.* Typhimurium, and continued to reduce populations throughout 5 d of storage (reductions: day 0 = 0.05-1.19 log; day 5 = 0.43-1.78 log); tap water and hot water (82ºC) treatments alone did not result in residual *S.* Typhimurium reductions during storage. In contrast, following initial microbial reductions via application of 1% lactic or 1% acetic acid washes, Dickson and Siragusa (1994) did not observe further reductions in inoculated *S.* Typhimurium, *E. coli* O157:H7, and/or *L. monocytogenes* Scott A populations on sterile beef tissue during simulated carcass chilling conditions (spray- and dry-chilling; 5ºC for 3 d).

Although residual bacterial reductions following antimicrobial treatments would be most advantageous, potential negative residual consequences associated with antimicrobial treatments should also be addressed. Samelis *et al.* (2001) examined the fate of pathogenic bacteria, including *S.* Typhimurium, in decontamination fluids when stored at 4 or 10ºC. All inoculated pathogens survived in nonacidic fluids, and *S.* Typhimurium populations increased by approximately 2 log CFU/ml at 10ºC (Samelis *et al.*, 2001; Samelis and Sofos, 2003). Therefore, although the extended effects of residual chemical interventions on carcass surfaces may provide additional antimicrobial effects, these solutions, if allowed to collect and trap pathogens within the carcass (Simpson *et al.*, 2006) or in the harvest-floor environment, can serve as sites of cross-contamination; potentially selecting for stress-adapted or hardier pathogens (Samelis and Sofos, 2003).

Following chilling and immediately before fabrication or boning, carcasses may be sprayed with antimicrobial chemical solutions (e.g., lactic acid) with the objective of further reducing and controlling contamination during fabrication and storage. It is well established that levels of microbial contamination increase rapidly and remain high on fabrication table or belt surfaces (Bacon *et al.*, 2002b). Although Barkocy-Gallagher *et al.* (2003) reported that incidence of *Salmonella* and *E. coli* found on beef carcasses prior to chilling was effectively reduced by using consecutive antimicrobial interventions, other studies found increased contamination in samples of beef subprimals and steaks indicative of additional product contamination during handling, fabrication, packaging and distribution (Bacon *et al.*, 2002b; Kain *et al.*, 1999; Sofos *et al.*, 1999b). Contamination levels should be kept low and sources of pathogens

should be avoided during fabrication in order to maintain product quality and safety during product storage, distribution and merchandizing. The product safety will finally be determined by proper processing or preparation and serving procedures which should eliminate any pathogens present without introducing new contamination. Previous pre- and post-harvest antimicrobial interventions assure that contamination levels are minimized in order to reduce the probabilities that failures in product processing or preparation for consumption may lead to foodborne illness.

Concluding Remarks

Although *Salmonella* and other pathogenic species of bacteria can be found throughout the beef production chain, the means are available to control these organisms. Success of pathogen intervention programs, however, is only achieved when used within their optimal parameters, and when recontamination events are avoided. As we have previously outlined, not all interventions are equally effective, and when sequence of application is varied, level of bacterial reductions may also vary. As more data from research validating the use of individual or combinations of intervention techniques become available the opportunity to select the most ideal sequence of interventions becomes more realistic. It should be stressed, however, that antimicrobial multiple hurdle programs should be used in conjunction with, and not in place of, good management and manufacturing practices in order to better control pathogenic organisms associated with the beef production chain. As we seek antimicrobial interventions that reduce any threat to human health we should ensure that any new and improved technologies developed or applied do not interfere with animal welfare or product quality, and should not lead to unpredictable risks, such as those involving selection of resistant pathogens. Antimicrobial interventions should not be used to remedy stresses on harvest-ready cattle via starvation, poor transportation protocols, etc, just as the interventions should not be applied as a substitute for good carcass handling practices.

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