factsheet
Pork Information Gateway

Salmonella in the Pork Production Chain

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Introduction

There is currently an explosion of research activity on food safety, including *Salmonella* contamination of pork and pork products. Salmonellosis is considered to be one of the most common foodborne illnesses in humans, with worldwide distribution and increased incidence in the United States during the last years (CDC,2000). Reasons for this include; increased public awareness of microbiological hazards of food, widespread distribution of virulent serotypes such as *Salmonella typhimurium* DT104, improved monitoring, increasing consumption of foods of animal origin, changes in consumer eating habits, and increased number of highly susceptible people (with impaired immune system).

The Economic Research Service (ERS) of the U.S. Department of Agriculture updated earlier estimates of the medical costs and productivity losses due to foodborne *Salmonella* infections in the United States. The update was based on an estimate of annual salmonellosis cases by the Foodborne Diseases Active Surveillance Network (FoodNet) and data on medical care for salmonellosis. Using this information, ERS estimated the annual economic cost of human illness due to foodborne *Salmonella* infections to be $2.3 billion (in 1998 dollars). Data on foodborne disease outbreaks suggest that 6-9% of foodborne *Salmonella* infections are associated with pork and pork products (Frenzen et al.,1999). Despite attempts to control foodborne pathogens in abattoirs and processing plants, a significant number of carcasses and pork products are still contaminated by pathogenic microrganisms such as *Salmonella*. According to Frenzen et al.(1999), nearly 9% of swine carcasses in large U.S. meat packing plants were contaminated by Salmonella in 1995-96, at the start of the period covered by the FoodNet salmonellosis estimate. However, in 1998, Zerby et al.(1998) observed a reduced *Salmonella* incidence of 4.6% in swine carcasses, demonstrating an improvement by the pork industry.

Food safety is a defining issue in the global pork market today, and *Salmonella* is becoming an increasing concern for the swine industry all over the world (Cravens,2000). In the United States, foodborne pathogens are being considered as another measure of overall pork quality (Dryden,1998). The European Union is now requiring all member states to initiate monitoring programs for *Salmonella* in swine (Kaesbohrer,1999).

For the swine industry (producers, slaughterhouses and packing plants) to be able to respond to this challenge, sound knowledge about the epidemiology of foodborne pathogens in general, and *Salmonella* in particular, will be essential. To this end, several funding agencies (including the National Pork Board) have provided considerable funds for research on foodborne pathogens over the last years (Davies,1997), and some initial information is now becoming available, underlining the complexity of *Salmonella* epidemiol-

ogy and the need for better understanding of how these organisms are introduced, disseminated and maintained along the pork production chain.

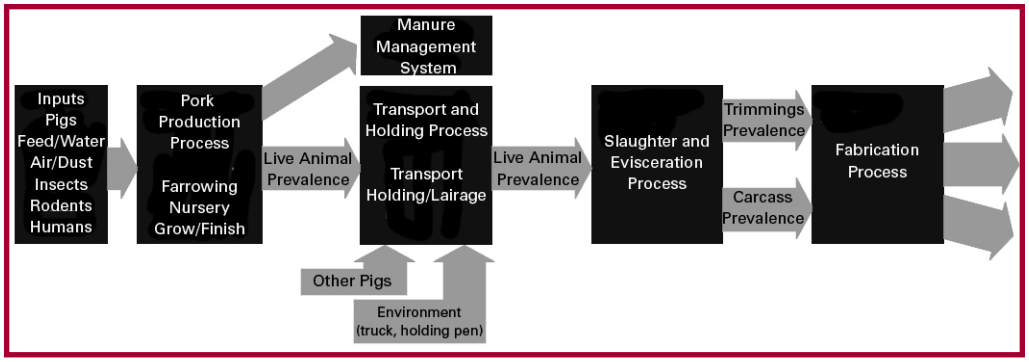

Fig. 1, Systems perspective on *Salmonella* sources in pork production and processing.

The objective of this paper is to review the scientific knowledge about *Salmonella spp.* sources in pork production, focusing on the impact of the farm, transport, holding, and slaughter processing.

Figure 1 shows a schematic representation of the pork production system, with emphasis on *Salmonella*. It shows potential inputs (sources) of *Salmonella* into the various processes of the system. Also shown are outputs from each of the processes. Note, that outputs from one process, or set of processes, serves as inputs to the next process. This figure posits that the output of *Salmonella* positive pigs from a particular process is the result of two general factors, the input(s) and the activities within the process. Examples of the later include, frequent mixing of animals, stress of transport, housing, and a variety of other management factors that affect the spread of all infectious diseases.

Salmonella Infection On-farm

Salmonella infections in swine are of concern for two major reasons. The first is the clinical disease in swine (salmonellosis), and the second is that swine are susceptible to infections with a broad range of *Salmonella* serotypes constituting a potential source of human exposure and illness.

Historically, transmission of *Salmonella* between hosts is thought to occur via the fecal-oral route of exposure. However, aerosol experiments in chickens and mice have shown that infections with *Salmonella* can be regularly achieved via this route (Clemmer et al.,1960; Darlow et al.,1961), giving support to the role that aerosols may also play in the transmission and dissemination of Salmonella in other hosts. Further studies indicated that the upper respiratory tract may be equally important in transmission and that the tonsils and lungs may be important sites for the invasion and dissemination of *Salmonella* in pigs (Fedorka-Cray et al.,1995; Gray et al.,1996). Collectively, these studies indicate that the traditional paradigm of fecal-oral transmission is not totally inclusive (Fedorka-Cray et al.,2000). While infection with large numbers of *Salmonella* may be required to initiate clinical disease (Salmonellosis), Fedorka-Cray et al.(1994) demonstrated that pigs infected with 104 colony-forming units (CFU) of *Salmonella typhimurium* develop a short-term carrier state, and Gray et al.(1995) demonstrated that a dose of 108 CFU results in persistent infection for at least 12 weeks. Several authors have demonstrated that pigs can shed *Salmonella typhimurium* for several months after an experimentally induced infection, with doses of 108 to 1010 CFU (Wilcock and Olander,1978; Wood et al.,1989; Nielsen et al.,1995). It is important to observe that all these studies were done using artificial infections (inoculations) of the studied animals with bacterial strains cultured *in vitro*. However, natural infections with organisms shed by other animals ("cultured *in vivo*") to the environment reveal that lower doses of *Salmonella* are effective in the establishment of infection (Hurd et al.,2001a). Bacterial pathogenicity and invasiveness is only fully manifested *in vivo*, where environmental conditions differ from those in laboratory cultures (*in vitro*) (Smith,1998).

The infected swine are an important reservoir and source for introduction and transmission of *Salmonella* on-farm. Excretion of *Salmonella* in feces onto the pen floor is sufficient to serve as a source for infection of other swine in the same pen or even in the same building (Wood, 1989; Fedorka-Cray et al., 1994; Weigel et al.,1999; Hurd et al., 2001a; Hurd et al., 2002). According to Friendship (1992), the most important means by which an infectious agent enters in a herd is by direct pig-to-pig spread, after the introduction of a carrier animal. However, Berends et al. (1996), suggested that contamination of endemic flora in finishing sites was the predominant source of infection of finishing pigs. Infection from breeding farms appears more important when pigs from various sources are mixed on finishing farms. Baggesen et al. (1997) isolated *Salmonella* from feces, pens, dust, equipment, and slurry during their studies in twelve pig farms,

with different levels of *Salmonella* infection. Ghosh (1972) and Davies et al.(2000) studied breeding herds where carriers were found frequently. In both studies the introduction of *Salmonella* in the studied herds was attributed to breeding animals. Also, Letellier et al.(1999) in their study found breeding animals as the source for the introduction and dissemination of *Salmonella* into herds.

Although horizontal transmission of *Salmonella* occurs through fecal-oral or aerogenous transmission, other vectors must be considered when discussing introduction and dissemination of the organism in the farms. The number of potential sources of *Salmonella* infection is seemingly endless. Observed sources of contamination include rodents, insects, birds, other animals, humans and contaminated feed and feedstuffs (Clarke and Gyles,1993; McChesney et al.,1995). Rodent fecal samples have been shown to contain up to 105 CFU of *Salmonella* (Henzler and Opitz,1992). During an investigation of *Salmonella* contamination, which involved 23 pig farms, Davies and Wray (1997) found a wide range of animals, including rats, mice, cats and birds to be infected. Cats and birds were associated with contamination of feed and grain stores, and rodents were involved in the perpetuation of infection in specific buildings on the farm. Flies and dust can also act as mechanical vectors that spread *Salmonella* throughout the environment (Greenberg et al.,1970; Khalil et al.,1994; Olsen and Hammack,2000). Cockroaches are found in almost any place. Much anecdotal evidence exists of cockroaches being a health risk and a vehicle for the spread of infectious organisms, including *Salmonella* (Bennett,1993). Cockoaches are only one part of the insect flora of domestic and rural environments. Beetles (lesser mealworm) are also frequently found in farms, and recent studies have shown that they are important reservoirs for *Salmonella* (Steelman and Waldroup; 2000).

Animal feed is a recognized source of pathogenic microorganisms for farm livestock (Linton and Jennet,1970; Davies and Hinton,2000). Harris et al.(1997) described a *Salmonella* prevalence of 2.9% in feeds and feed ingredients taken from farm environments. Feed trucks have also been implicated as a source for feed and feedstuffs contamination (Fedorka-Cray et al.,1997a). Feed containing ingredients of animal origin is a potential source of Salmonella infection to herds, but it should be emphasized that ingredients of vegetable origin can also be a source of *Salmonella*-contaminated feed. AFDA survey of animal and plant protein processors demonstrated that 56.4% of the animal protein and 36% of the vegetable protein products taken from 124 processors were positive for *Salmonella* (McChesney et al., 1995). However, the most frequent Salmonella serotypes isolated from feed are rarely the most prevalent in animals. Even so, the potential for contamination exists, and the consequences can be serious (Davies and Hinton,2000).

Water is not as likely a source of infection unless surface water is used for consumption or pigs have access to recycled lagoon water (Schwartz,1999). However, rodents and birds can contaminate the water, increasing the chance of the spread of infection within the herd. *Salmonella* have also been shown to form biofilms on glass and chlorinated polyvinyl chloride (CPVC) pipes (Jones and Bradshaw,1996). This could enable the organisms to effectively colonize water pipe lines in the farms, constituting a potential of maintenance and dissemination of *Salmonella*.

Although wild birds are recognized as carriers of *Salmonella*, evidence suggests that infected birds are rarely found. Usually, the *Salmonella*-contaminated environment is regarded as the main source of infections among wild birds, with the organisms being acquired during food gathering and drinking (Murray, 2000).

Farm environments (facilities and equipment) may become persistently contaminated with *Salmonella* following the introduction of the bacteria in the herd. Environmental and management practices may contribute to the dissemination and maintainance of *Salmonella* within herds. Davies and Wray (1996) compared two methods of disposal of calf carcasses artificially contaminated with *Salmonella typhimurium* for their capacity to eliminate the bacteria and spread to the surrounding environment. It was found that the frequency of *Salmonella* isolations decreased more rapidly from the burial pit than from the decomposition pit (4 months compared with 6 months to disappear). During this study, a large population of blowfly larvae developed within 2 weeks in the decomposition pit and these were *Salmonella*-positive. *Salmonella* were also found in wildbird droppings in the vicinity of the pit for a period of 4 weeks after loading the pit. Nearby drainage ditches were *Salmonella*-positive, initially close to the pit but, after 3 weeks, up to 12 meters along the drain.

As mentioned, *Salmonella* may persist in the environment for long periods, and cleaning and disinfection routines procedures may not always be efficient in eliminating the contamination. Bacterias of the genus *Salmonella* are hardy, surviving freezing and desiccation very well, and persisting for weeks, months, or even years in a suitable organic substrate (Schwartz,1999). The temperature range for growth of *Salmo-*

nella is between 5.5 and 45°C (Doyle and Mazzotta, 2000). Modern intensive livestock production has created problems of excreta disposal, and *Salmonella* may survive for long periods in infected feces and slurry, where their survival is dependent on a number of factors, especially the serotype and the climatic conditions (Wray,1994). Gray and Fedorka-Cray (1995) found that *Salmonella choleraesuis* survives in dry feces for at least thirteen months postshedding, demonstrating the importance of cleaning organic matter from the environment. Davies and Wray (1997) found high levels of *Salmonella* persisting in pig pens after disinfection. Gebreyes et al.(1999) detected *Salmonella* in drag swabs of floors from barns after cleaning and disinfection, and before pig placement in 82% of the studied cases. In some of the studied cases, finisher pigs shed a *Salmonella* serotype that had been found on drag swabs.

In three persistently infected herds, Dahl et al. (1997) studied the effects of moving pigs to clean and disinfected facilities, at different ages before *Salmonella typhimurium* had been detected either serologically or bacteriologically. No detectable infection was observed at slaughter either serologically or bacteriologically in the moved groups of pigs, whereas a proportion of the pigs raised at the same time in the continuous systems on the farms were found to be infected. Fedorka-Cray et al.(1997b) were also able to raise piglets free of infection with *Salmonella enterica* serovars up to six weeks of age, by removing the piglets from infected herds to isolation facilities when they were weaned at 10-21 days of age. The results of these studies demonstrate that the environment plays a critical role in the *Salmonella* infection epidemiology in swine herds. As mentioned, an important risk factor for introducing disease to a swine herd is direct exposure to infected animals. However, humans, may act as mechanical vectors transmiting pathogens among groups of pigs. They are believed to be another important risk factor for the introduction and dissemination of pathogens in swine herds (Moore,1992; Friendship, 1992). Amass et al.(2000) conducted a study evaluating the efficaccy of boot baths in biosecurity protocols in swine farms. Results of this study demonstrated that most of the on-farm washing and disinfection of boots are not efficacious for eliminating the contamination with pathogens.

An interesting study was reported by Letellier et al.(1999), showing the complexity of *Salmonella* epidemiology in swine herds. The objective of this study was to identify, in herds known to be positive for the presence of *Salmonella*, possible sources of contamination, and evaluate the prevalence and distribution of *Salmonella* at the different levels in an integrated swine production system. In the herds studied, many environmental samples such as water taken in the pen, boots, floors, doors, rodents or rodent's nests were found to be contaminated. Although it was not concluded that these positive samples were the source of the infection for swine, there is no doubt that they could be involved in subsequent contamination if appropriate measures are not taken. Flies were positive for *Salmonella* on the highly contaminated farms and as mentioned before, they may be involved in the dissemination of *Salmonella* in the environment as carrier of microorganisms (Morse and Duncan,1974; Khalil et al.,1994). It is also important to note that in these studied herds, dead animals were considered as possible sources of contamination, and that boots of animal caretakers were also found positive for *Salmonella* indicating that a particular attention should be given to improve the desinfection of boots to avoid the dissemination of *Salmonella*, in agreement with Amass et al.(2000).

Transport and Lairage Effect on *Salmonella* Infection in Pigs

It has been shown by a number of studies that substantial numbers of pigs are carrying *Salmonella* when arriving in the abattoirs (Kampelmacher et al., 1963; Riley,1970; Harvey et al., 1977). Several studies have demonstrated that the intestinal tract and its associated lymph nodes are frequently infected and provide a source from which Salmonella may be spread in the abattoir, contaminating carcasses and other food products (Craven and Hurst,1982; Morgan et al.,1987). Morgan et al.(1987) found in their study, that the source of carcass contamination was primarily intestinal *Salmonella* infections and the extent of carcass contamination was determined by the number of *Salmonella* entering the abattoir in the intestine of slaughtered pigs. Also, Widders et al.(1996) showed that *Salmonella* levels in carcasses were largely determined by Salmonella levels in pigs supplied to abattoirs. Although much of the *Salmonella* contamination of pork and pork products occurs within abattoirs during processing, infected pigs leaving the farm are considered as the original source of abattoir contaminations. According to Berends et al.(1997), live animals that carry *Salmonella* are 3-4 times more likely to end up as a positive carcass than *Salmonella*-free animals.

Transport time, feeding management (feed withdrawal), environmental contamination, commingling, and

length of time in lairage all may affect the *Salmonella* infection levels in groups of pigs (Williams and Newell,1968; Craven and Hurst,1982). Shedding of *Salmonella* from inapparent carriers may be exacerbated by a long list of stressors, including handling and commingling of pigs, transportation, concurrent diseases, and food deprivation Stress represents the reaction of the body to stimuli that disturb its normal physiological equilibrium or homeostasis, which have significant impact on the immune system in general (Khansari et al.,1990). During loading, transport, unloading and commingling, pigs are exposed to various stressors before slaughter, including noise, unfamiliar smells, vibration, changes in temperature, breakdown of social groupings and food deprivation (Warriss et al.,1992). The status of the immune system will depend upon the net effect of these changes (Khansari et al.,1990). Consequently, many believe that the number of pigs shedding *Salmonella* will be increased after all these stressors, as will their susceptibility to new infections. It is important to consider here, that stress affects the immune system (Khansari et al.,1990), and consequently the immune status of the animals subjected to stressors. However, there is no conclusive data showing a direct association between stress or immune status and increased shedding or susceptibility to *Salmonella* infections in swine. Some studies have shown an indirect association. According to Craven and Hurst (1982) and Morgan et al.(1987), the prevalence of infection within a group of pigs continues to increase with increasing length of stay in the holding pens prior to slaughter, rising by about 50% for each 24-hour period. Williams and Newell (1970) showed, in a small group of pigs, that shipment (transport) of pigs led to increased shedding patterns of *Salmonella*. As a result of shipment, carrier animals begin to shed higher levels of *Salmonella* that may be spread within the group during shipment, and also at the slaughterhouse, during lairage. More recently, Isaacson et al.(1999a) showed that pigs experimentally challenged with *Salmonella typhimurium* exhibit increased shedding after transportation. Isaacson et al.(1999a,b) found conflicting results in studies to determine the effect of feed withdrawal and transportation on the shedding of *Salmonella typhimurium* in experimentally challenged pigs. Collectively, the results of these experiments indicate that there is an interaction between feed withdrawal and transportation that can lead to increased shedding of *Salmonella* by pigs. Morrow et al.(1999) conducted a study that examined the effect of feed withdrawal on the prevalence of *Salmonella* in cecal contents at slaughter. Results of this study indicate that feed withdrawal only prior to slaughter did not increase the prevalence of *Salmonella*, but the frequency that feed was withdrawn before slaughter was associated with increased *Salmonella* isolation.

The physiological effect of lairage, close contact with other pigs, and environmental exposure also may be important determinants of *Salmonella* prevalence at slaughter. The increased stocking density that usually occurs in the holding pens at the slaughterhouses may lead to crossinfections (Morgan et al.,1987; Morrow et al.,1999). Astudy of the effect of time spent in lairage on *Salmonella* presence in the caecum and on skin surface of 450 slaughter pigs from a single producer was conducted by Morrow et al.(1999). Pigs were tested at two abattoirs, after 18, 42, and 66 hours spent in lairage. The *Salmonella* isolation rate from caecum and carcass surfaces increased significantly with increasing time spent in lairage, being isolated from the caecum of 18.5% of pigs held less than 24 hours in lairage, 24.1% of pigs held a further 24 hours, and 47.7% of pigs held for 66 hours in lairage before slaughter. The *Salmonella* isolation rates from carcasses were 9.3%, 12.8%, and 27.3%, respectively. This study was conducted in two different slaughterhouses, where one of them had a higher *Salmonella* isolation rate from pigs than the other. The number of pigs held for 24 hours in lairage with *Salmonella* in their caecum were significantly different between the two abattoirs. This difference was suggested to be probably related to lairage management. Observations in this study suggest that pen size and hygiene influence the build-up of *Salmonella* in pigs during lairage. Pigs held in the first abattoir continued to have a higher prevalence of *Salmonella* in caecal contents, whereas the build-up of *Salmonella* in pigs at the second abattoir was slower. The size of the pens in the abattoirs was different, and in the second one the hygiene was much better than in the first one. As noted in the study by Hurd et al.(2001b), there was no difference in isolation rates for pigs shipped direct to slaughter and those experiencing 18 hours lairage, in a clean and disinfected isolation barn. It is important to note that in the United States, most abattoirs avoid holding pigs more than 6-8 hours. However, a minimum of two hours holding is encouraged to improve meat quality. This is thought to be the minimum time needed for pigs to recover from the stress of transport (Warriss et al.,1992).

A few studies are beginning to suggest that even this short term (2-3 hours) holding may be a significant source of *Salmonella* infection. In a study by Hurd et al.(2001b) a large difference (3.4% vs. 71%) was observed in the proportion of pigs positive by on-farm fecal testing and the same pigs tested by culture of gut associated samples collected at slaughter (ileocecal lymph node, cecal content, distal colon content). This observation has been made by others (Kim et al.,1999; Proescholdt et al.,1999). In these three studies pigs were hold 2-3 hours at the abattoir. The lack of lairage effect and the variety of *Salmonella* serotypes

found at slaughter, compared to the farm, suggest that an external source of infection was more important than stress for increasing *Salmonella* isolation rates (Hurd et al.,2001b).

McKean et al.(2000) conducted a study to address differences in samples collected on farm (feces) and after slaughter (ileocecal lymph node, cecal content, distal colon content). Market pigs (penmates) were randomly assigned to be necropsied on the farm of origin or at the abattoir, after transport in disinfected trailers, and 2-3 hours holding. The same samples (feces, ileocecal lymph node, cecal content, superficial inguinal lymph node) were collected at both locations. For five of the six farms included in the study, the isolation rate was significantly higher for penmates after transport and holding. The average prevalence rate for on-farm necropsied pigs was 8.5%, compared to 40.8% for pigs necropsied after transport and short-term holding at a commercial abattoir.

There is evidence to suggest that contamination of the gastrointestinal tract and invasion of gut associated lymph nodes is feasible in 2-3 hours. Clemens et al. (1975) have demonstrated that it is physiologically possible for a fluid marker to reach the cecum in two hours and a 2mm particle to reach the cecum in four hours. Fedorka-Cray et al.(1995) found that *Salmonella* could be recovered from the cecum of intranasally inoculated, esophagotomized piglets (6-8 weeks old) within three hours. Hurd et al.(2001) demonstrated that market swine exposed to a low dose (1.5 x 103 CFU) of *Salmonella typhimurium* in feces deposited on the floor by shedder pigs, will have infected ileocecal lymph nodes and a contaminated gastrointestinal tract in as little as two hours. Additionally, they demonstrated a seven-fold increase in prevalence when comparing on-farm and abattoir necropsied pigs, with many new serotypes recovered at the abattoir (Hurd, et al. 2002).

Preharvest Conclusion

It is clear that *Salmonella* is a complex multifactorial problem. Its management must go beyond the typical infectious disease (pig-to-pig) paradigm to include the dynamic, changing, ecosystem perspective. This system, as represented in Figure 1, is constantly in flux; receiving inputs and processing them into *Salmonella* infected pigs, among other things. Additionally, the *Salmonella* organism is complex, with 2,200 different serotype, and hardy. Diligence must be applied to prevent its introduction and reintroduction from a variety of sources, such as new pigs, feed, birds, rodents, insects, humans, etc. The presence of *Salmonella*, as well as its level, in these sources, must be monitored.

Once *Salmonella* is in a production system, which is common, efforts must be made to reduce its spread and proliferation. In most cases, eradication is not feasible. Control efforts should be directed towards reducing the prevalence of *Salmonella* carriers that leave the production system. However, other than general hygiene and disease control principles, there is limited research on specific management practices that effect within herd prevalence.

Once pigs leave the farm, efforts should be directed towards reducing *Salmonella* exposure and stress. Some stress is inevitable during transport and lairage. Therefore, reduction of exposure levels in the truck and holding pens is more likely to reduce prevalence, than attempts to reduce stress. Commingling during transport and lairage should be reduced. Interventions to reduce environmental loads in the trucks and holding pens need to be developed and tested. Steps to reduce the pigs' susceptibility to acute infection, during marketing, should also be evaluated.

Additionally, work is needed on methods to estimate the *Salmonella* prevalence in the production system. Culture methods and sampling protocols need to be standardized to allow comparison of results among researchers. Antemortem tests, such as serology used in Denmark need to be evaluated in US systems. Additionally, research is critically needed on management or risk factors within the production system, to reduce the prevalence. Lastly, the presence of *Salmonella* in the manure and its effect on the environment and public health need to be evaluated.

Once the pig is stunned and enters the kill floor, it enters an entirely different set of processes, generally termed post-harvest. The impact of those processes on the levels of *Salmonella* in finished pork product are reviewed below.

Salmonella Contamination During Pork Processing

It is assumed that the muscle tissue of healthy animals entering the slaughter establishment is free of microorganisms (Ayres, 1955). However, intrinsic bacteria, that is bacteria which occur in the deep muscle tissue of healthy animals, have been reported for many animal species (Ingram, 1964; Ingram and Dainty, 1971; Robinson et al., 1953). The most frequently characterized intrinsic bacteria are *Clostridium spp.* (Canada and Strong, 1964; Narayan, 1966; Zagaevskii, 1973; Jensen and Hess, 1941). However, *Salmonella* has not been reported as intrinsic bacteria in the muscle tissue of healthy animals, so the assumption for the following discussion will be that *Salmonella* that contaminate the muscle tissue of pigs are from extrinsic sources (gastrointestinal tract, lymph nodes, external carcass surfaces, and environmental sources). Berends et al. (1997) reported that carcasses produced from live animals that carried *Salmonella* were three to four times more likely to test positive for *Salmonella* than were carcasses from animals that did not harbor *Salmonella*.

1. Stunning/Sticking/Bleeding With the exception of the sticking process, the opportunity for *Salmonella* contamination of carcasses is limited to bacteria which are already on the animal at the time of stunning, or those which may be transferred by common contact surfaces, most notably the conveyor. Dickson (1997) reported that approximately 50% of the hog carcasses sampled on the bleeding rail were positive for *Salmonella*, and speculated that most of this was due to on-farm contamination. However, cross contamination between carcasses from the conveyor cannot be ruled out as a possible source. Cross contamination is a well-recognized concept within food microbiology and food processing. Briefly, cross contamination simply means the transfer of microorganisms from a contaminated food item to a non-contaminated food item by some common contact source, whether that be air, water or equipment surfaces. From the available scientific literature, it seems that cross contamination does occur between carcasses as a result of unsanitized equipment. While there is apparently no data on the impact of the conveyor on *Salmonella* contamination on the exterior surfaces of hog carcasses, there is some relevant data on the subject from poultry processing.

The strongest evidence of cross contamination comes from two studies using a non-pathogenic marker bacterium. Mead et al. (1975) artificially inoculated turkey carcasses with *Escherichia coli* K12 and followed this bacterium through the processing plant. The authors processed two of the artificially inoculated carcasses, followed by conventional noninoculated carcasses, and were able to recover the marker bacterium from the 200th. carcass afterwards after de-feathering and also after evisceration. Use of water chlorinated to 20ppm did not appreciably affect these results. Mulder et al. (1978) conducted similar experiments with chicken carcasses, and examined carcasses after scalding and after de-feathering. At both sampling locations, the authors consistently documented the spread of the marker bacterium, again *E. coli* K12, from inoculated carcasses to uninoculated carcasses, and concluded that "external contamination of carcasses leads to cross contamination during scalding and plucking". Clearly, it is theoretically possible that *Salmonella* could be transferred from a live hog to the surface of the conveyor, and that this contamination could then be transferred to another live hog that was previously not contaminated with *Salmonella*.

The impact of sticking on contamination of pork with *Salmonella* is less clear. Aclassic study by Jensen and Hess (1941) evaluated the process of sticking, and suggested that bacteria could enter the bloodstream during the sticking. These conclusions were based on the fact that fewer bacteria were found in the blood retained in the hearts of hogs "sterilely" stuck, as compared to those that were septically stuck. However, they also noted that when cultures of *Escherichia coli* were added to blood drawn from a live hog, the bacteria could not be recovered after two to five hours, and they attributed this to the bactericidal activity normally associated with blood.

For *Salmonella* to enter the bloodstream of a hog during the sticking operation, several events would have to occur. The first is that *Salmonella* would have to be present at the exact point of the stick wound. Secondly, the bacteria would have to be carried into the bloodstream of the hog by the knife, either from previous contamination by another hog or from material at the site of the stick wound. Research has shown that *Salmonella* may be carried on improperly sterilized knives (Peel and Simmons, 1978). While there might be a reasonable probability of these events happening, the individual cells would be rapidly dispersed throughout the entire bloodstream, resulting in a rapid dilution of the initial population. In an average, the blood volume is approximately 6 liters (Swenson 1975) for an 100kg hog presented for slaughter. This dilution, coupled with the documented bactericidal properties of the blood, suggest that the stick would not be a major source of *Salmonella* contamination of the muscle tissue. In addition, the site of

the stick would itself is normally trimmed out at a later point in the process, removing any bacteria which may have adhered to the tissue. The USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS,1999) indicated that the sticking operation was not a critical control point (CCP).

2. Scalding In the United States, operating parameters for scald operations range from 57.7–61°C (136–142°F) for three to eight minutes. A typical scald operation would be 58.8°C (138°F) for six minutes. Typical reported decimal reduction values (D10 values) for *Salmonella enterica var. Typhimurium* range from 8.5 minutes at 55°C (131°F, Elliott and Heiniger, 1965), 2.34 minutes at 56°C (133°F, Humphrey et al., 1981), 0.63 minutes at 58°C (136°F, Humphrey et al., 1981), to 0.2-0.9 at 60°C (140°F, Baird-Parker et al., 1970). During the colder months, it is common to add processing chemicals to the scald water to facilitate hair removal, which raises the pH of the scald water to approximately pH 10. As the pH of the water is shifted away from neutrality, the D10 values of *Salmonellae* generally decline. As an example, *Salmonella enterica* var. *Typhimurium* has a reported D10 value of 6.1 minutes at pH 7.6 at 52°C (125°F, Humphrey et al., 1981), but only 0.175 minutes at pH 10 at the same temperature.

The microbiological data suggests that the majority of *Salmonella* would not survive a scald process of 58.8°C for six minutes. Based on the data of Humphrey et al. (1981), this combination of time and temperature would result in greater than a 9 log10 cycle (9 D) reduction of *Salmonellae*. This suggests that cross-contamination with *Salmonella* between carcasses in the scald tank would be an unlikely event.

All of the previous data was based on planktonic (free-floating) cells of Salmonella in broth cultures. In reality, incoming *Salmonella* on hog carcasses are most likely embedded in either fecal material or other environmental soil on the carcass, or may in fact be in the hair follicles. In either of these cases, the *Salmonella* would be at least partially protected from both the heat and pH of the scald water and would have different survival characteristics from the planktonic cells of the experiments. Two reports may illustrate this point. In the first, hog carcasses sampled after a typical scald procedure showed dramatically reduced populations of coliforms and were consistently *Salmonella* negative, when compared to similar carcasses prior to scalding, of which half were positive for *Salmonella* (Dickson, 1997). In contrast, a different processing establishment, which used a scald time that was approximately half of the typical process, had frequent *Salmonella* positive carcasses after chilling (Dickson, 1996). While the difference in microbiological status of the carcasses cannot be solely attributed to the scalding operation, scalding is an important antimicrobial process in hog processing. The USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS,1999) indicated that the scalding operation was not a CCP.

The microbiological issues with skinned carcasses are similar to those with beef carcasses, where the hides of the beef are routinely removed as part of the process. Hide removal offers many opportunities to contaminate the carcass, in part because there is no prior treatment of the hide to remove contamination. As a result, the mechanical process of removing the hide may result in sporadic, random contamination of the edible tissue underneath. Skinned carcasses typically have higher mesophilic aerobic populations, but slightly lower coliform and generic *Escherichia coli* populations (Dickson, 1997). Skinning operations were included in the draft USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS,1996b), although these were subsequently dropped in the final plan (USDA-FSIS, 1999). In the original draft plan, hide removal was not indicated as a CCP, although it was recognized as an operation that could be the source of a potentially significant food safety hazard.

3. De-hairing/Singeing/Shaving The scalding operation significantly reduces the overall microbial population on the skin of hog carcasses (Sorqvist and Danielsson-Tham, 1986). However, dehairing equipment is known to be a reservoir for bacterial contamination. Gill and Bryant (1993) reported that populations of *Salmonella* were as high as 100,000 per gram of detritus material found in commercial de-hairing machines, although the authors did not recover *Salmonella* on the carcasses exiting the equipment. The presence of relatively large populations of *Salmonella* in the detritus found in the machines suggests that some *Salmonella* survived the scalding operation and were subsequently removed.

Ayres (1955) speculated that the mechanical action of the de-hairing machines could introduce bacteria into the skin surface by scratching. The potential for contamination during the de-hairing process is illustrated in a study that showed that the mesophilic bacterial populations on hog carcasses increased after the de-hairing operation, when compared to the populations before de-hairing (Gill and Bryant, 1992). In a similar study, Nerbrink and Broch (1989) reported increases in *Enterobacteriaceae* populations on hog carcasses after de-hairing. However, the previously cited report also found reductions in mesophilic

aerobic bacteria and in *Enterobacteriaceae* populations after singeing, which suggest that singeing has an antimicrobial effect on the bacterial populations. The reported *Enterobacteriaceae* populations were below detectable limits after singeing. Saide-Albornoz et a;. (1995) reported that 4.4% of the carcasses were positive for *Salmonella* after singeing and polishing. The USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS,1999) indicated that although the de-hairing/singeing/shaving operation was not a CCP, the possibility of biological contamination was reasonably likely to occur.

4. Head Drop or Removal There is a reasonable probability that the external surfaces of the jowls and the mandibular lymph nodes may be contaminated with Salmonella. The external surfaces of the jowl may be contaminated from production sources, or from those processing operations previously discussed (stunning, de-hairing). *Salmonella* contamination of the mandibular lymph nodes would be attributable to exposure of the live animal to the bacterium. The two possible modes of contamination have distinctly different implications for the presence of *Salmonella* in edible pork products.

External contamination of the jowls would limit contamination either to the specific carcass, or possibly other carcasses through cross contamination from the head dropping equipment. Although there is no specific data to indicate that this can in fact happen, the inference can be drawn from evidence of cross contamination from other equipment. Head dropping equipment is routinely sanitized, but it is unlikely that this sanitizing program would exclude the possibility of cross contamination.

The presence of *Salmonella* in mandibular lymph nodes would result in the possibility of contamination within the tissue itself. Mandibular lymph nodes may be inadvertently trimmed from the head and included with the muscle tissue. This edible muscle tissue is most commonly used for further processed products (such as frankfurters and luncheon meats) which are typically cooked to destroy microbial pathogens. Because of this, the potential significance to human health of *Salmonella* contamination of this product (*head* meat) is reduced, when compared to edible products which may reach the consumer in an uncooked state. The USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS,1999) indicated that although the head drop operation was not a CCP, the possibility of biological contamination was reasonably likely to occur.

5. Evisceration Evisceration is one of the operations that has the greatest potential for *Salmonella* contamination. Damage occuring to the internal organs during normal removal of the viscera has the potential to distribute stomach, intestinal or cecal contents throughout the peritoneal and pleural cavities. Since evisceration, as it is commonly practiced, is a manual operation, contamination is of a random nature and typically would affect only the specific carcass in which the break occurred. Bacterial populations of total coliforms and generic *Escherichia coli* on both scalded and skinned carcasses were either unchanged or slightly lower after evisceration (Dickson, 1997). Nerbrink et al. (1989) reported that populations of *Enterobacteriaceae* were essentially unchanged after evisceration, although Berends et al. (1997) reported a slight increase in these same microbial populations after evisceration. Salmonella were detected on 2% (scalded) and 6.7% (skinned) carcasses after evisceration, in comparison to 0% after scalding or 5% after skinning (Dickson, 1997).

The USDA–FSIS generic HACCP plan for pork slaughter (USDAFSIS, 1999) indicated that although the evisceration operation was not a CCP, the possibility of biological contamination was reasonably likely to occur. Borch et al. (1996) suggested that evisceration was a CCP, with a similar justification. The difference in the two opinions may be in the fundamental approach to HACCP. The philosophy of HACCP in the United States has been that CCP's must be controllable, and the evisceration operation in animal processing is viewed generally as an operation that has limited means of control.

6. Final Inspection/ Trimming/Final Wash The final inspection is used to identify any observable defects that must be removed. These defects are removed by trimming, and then the carcass is subjected to a final wash. Prasai et al. (1995) reported aseptic trimming procedures reduced the populations by approximately 3 log10 cycles on beef carcasses. Reagan et al. (1996) reported that trimming reduced the total aerobic populations on beef carcasses by approximately 1.3 log10 cycles. The study by Reagan et al. was conducted using standard industry practices for trimming in several processing plants, while the study of Prasai et al. was limited to one plant with trimming performed under optimal, if not aseptic, conditions. Manual trimming also raises the issue of cross contamination with knives (Peel and Simmons, 1978), which has previously been discussed. Trimming can be used to remove visible defects, but obviously is of little value for microbial contamination, which cannot be visually identified.

The final wash, when combined with the application of an anti-microbial treatment, can potentially reduce the populations of bacteria on animal carcasses (Dickson and Anderson, 1992). The use of hot water (Gill et al., 1995) or hot water in combination with organic acids (Barkate et al., 1993; Dickson, 1998) has been shown to be an effective method of decontaminating hog carcasses. In addition, trisodium phosphate, an alkaline food additive, has also been demonstrated to have anti-microbial effects on the surface micrflora of hog carcasses (Morris et al., 1997). The final carcass wash is a "whole carcass" treatment, as compared to the "spot" treatment of manual trimming, and therefore is effective in reducing microbial contamination that may be missed by visual inspection of the carcass.

The USDA–FSIS generic HACCP plan for pork slaughter (USDAFSIS, 1999) indicated that the final inspection and trimming operation was not a CCP, although the final wash with an antimicrobial treatment was recommended as a CCP. Borch et al. (1996) suggested that the final inspection was a CCP, although their concern was related to contamination from inspection. The context of the Borch study was the European processing scheme, where carcasses are generally not washed after the final inspection.

7. Chilling There are currently three commonly used chilling systems in use for hog processing: conventional forced air chilling, spray chilling, and blast chilling ("deep" chill) systems. The conventional chill system uses standard refrigeration techniques and air movement to remove heat from the carcasses. Spray chilling is a variation of this process, combining conventional refrigeration with a system that sprays cold water on the carcasses. The principal of spray chilling is that evaporative cooling of spray chilling results in a more rapid removal of the heat from the warm carcass. In addition to the advantage in cooling offered by spray chilling, the process also reduces carcass shrinkage in the coolers, which has been estimated to be approximately 25g per kilogram of carcass weight (Jones et al., 1988). Blast chilling involves moving the carcasses through a blast chiller (essentially a freezer) to rapidly chill the external surfaces of the carcass, and then moving the carcasses into a conventional chiller to allow them to equilibrate. Blast chilling has been reported to reduce shrinkage over conventional chilling (Tarrant, 1989).

From a microbiological perspective, conventional chilling and blast chilling offer an additional advantage, in addition to a reduction in temperature. Both conventional and blast chilling dry the exposed surfaces of the carcasses to a point where there is usually insufficient moisture to support microbial growth, and often results in a reduction in overall microbial populations. In contrast, spray chilling results in a more rapid eduction in the surface temperature of the carcasses (where the microbial contamination is located), but with the obvious result of a high moisture content on the surface, therefore negating the anti-microbial effects of drying. Ingram and Roberts (1976) reported a consistent reduction in populations of *Enterobacteriaceae* and coliforms, as well as a reduction in the number of carcasses positive of generic *Escherichia coli* after chilling, when compared to those before chilling. Although they did not describe the method of chilling, the date and location of the study preclude the use of both spray chilling and blast chilling. Greer and Dilts (1988) reported that although spray-chilled carcasses had slightly lower surface temperatures after spray chilling, the mesophilic bacterial populations were lower on dry-chilled carcasses. The reported reduction in bacterial populations were attributed to surface drying, when the water activity fell below the minimum for bacterial growth (Christian, 1980). There is little scientific data available on the microbiological affects of blast chilling, although Jones et al. (1991) examined the effects of cryogenic chilling on meat. These researchers reported that immersion in liquid nitrogen, which they compared to blast chilling, did not result in a significant change in the mesophilic microflora on pork. These same researchers reported a significant reduction in the population of *Salmonella typhmiurium* when artificially inoculated samples were subjected to a similar cryogenic cooling process. Gigiel et al (1989) reported that total mesophilic populations on rapidly chilled hog carcasses either slightly decreased or slightly increased, depending on the location of the samples examined from the carcasses.

Carpenter et al. (1973) reported that 23% of hog carcasses from one slaughter establishment were contaminated with *Salmonella* after conventional chilling, while no carcasses from three other establishments were positive. Saide-Albornoz et al. (1995) reported that 0.4 % of the carcasses sampled in five Midwest processing establishments were positive after 24 hours of chilling. Dickson (1997, 1996) found *Salmonella* contamination rates of 0% to as high as 9%, varying between different slaughter establishments. While the higher rates of contamination were observed in establishments using spray chilling and lowest in those using blast chilling, it is unlikely that the observed differences in contamination were directly correlated to the method of chilling. Roberts et al (1980) noted that the bacterial populations on carcasses after processing were the result of the level of hygiene practiced at all of the various stages in processing. USDA-FSIS (USDA-FSIS, 1996) baseline survey for swine indicated an overall *Salmonella* contamination rate of 8.7% for hog carcasses.

The USDA–FSIS generic HACCP plan for pork slaughter (USDA-FSIS, 1999) indicated that chilling was a CCP because of the possibility of the outgrowth of biological hazards if proper chilling procedures were not followed. The chilling operation primarily affects those carcasses which are already contaminated with *Salmonella*. However, transfer of microorganisms between meat surfaces by direct contact has been demonstrated (Dickson 1990), suggesting that the physical handling of carcasses in the coolers may be worth consideration as a possible source of cross contamination between carcasses.

8. Fabrication The cutting of pork carcasses into smaller components can result in the transfer of contamination from inedible tissue to edible tissue. Operations which directly involve removing the hide from muscle tissue (removing loins, skinning hams) are of particular concern. Equipment and knives have the potential to become contaminated by contact with the hide, and then this contamination may be spread to the edible tissue. Research has shown that *Salmonella* may be carried on improperly sterilized knives (Peel and Simmons, 1978). In a similar manner, contamination from one carcass may be spread to tissue from another, uncontaminated carcass by contact with common surfaces, such as knives, processing equipment or conveyor belts. The primary issues with *Salmonella* contamination in the fabrication operation are the transfer of the bacterium from the hide to edible tissue, and the transfer of *Salmonella* from one carcass to the edible tissue of another carcass. Astudy of air quality in pork processing establishments indicated that the mesophilic aerobic microbial population found in the air in cutting rooms did not differ appreciably from populations found in other parts of the processing operation, most notably on the slaughter side of the operation (Kotula and Emswiler-Rose, 1988).

Post Harvest Conclusion

Salmonella enters the slaughter establishment with the live animal. As the animal and then carcass is processed, the bacterium may be transferred from the hide or intestinal contents to the edible tissue of the specific carcass. In addition, opportunities exist at specific points in the process for *Salmonella* to be transferred from one carcass to another. The level of hygiene, both of the dressing procedures and the general condition of the plant, may have a profound influence on the overall level of *Salmonella* contamination. Several operations within the process are inhibitory to either the growth or to the survival of the bacterium, and specific interventions may be incorporated into the process to reduce the likelihood or occurrence of survival. However, the process cannot guarantee that *Salmonella* will not ultimately contaminate the edible tissue. There is no single specific step in the process, which results in a product that is absolutely free of *Salmonella*. While the level of *Salmonella* contamination within a given establishment may be reduced by modifying or improving the process, there will be no absolute assurance that all of the product is free of *Salmonella* until the incoming live hog can be assured to be free of *Salmonella*.

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