Pork Safety Fact Sheet

Salmonella in the Pork Production Chain

Introduction

Salmonella is one of the most important foodborne pathogens worldwide, and products of animal origin constitute common infection sources. Food safety is a defining issue in the competitive global pork market today, and *Salmonella* is a major concern for the swine industry all over the world. It is estimated that 80.3 million cases of foodborne salmonellosis occur annually in the world (Majowicz et al., 2010). In the U.S., *Salmonella* is the second leading cause of foodborne illness, and the leading cause of hospitalization and death (Scallan et al., 2011). Although the precise number of human salmonellosis cases directly attributable to pork or pork products is difficult to determine, reported estimates range from < 1% to 25% (Berends et al., 1998; Hald et al., 2004; Miller et al., 2005; Guo et al., 2011).

For the swine industry (producers and processors) to be able to respond to this challenge, sound knowledge about foodborne pathogens in general, and *Salmonella* in particular, is essential. Therefore, we compiled information from a number of studies conducted around the world investigating the ecology and epidemiology of *Salmonella* in pork production, focusing on the impact of the farm, transport, holding, and harvest processing.

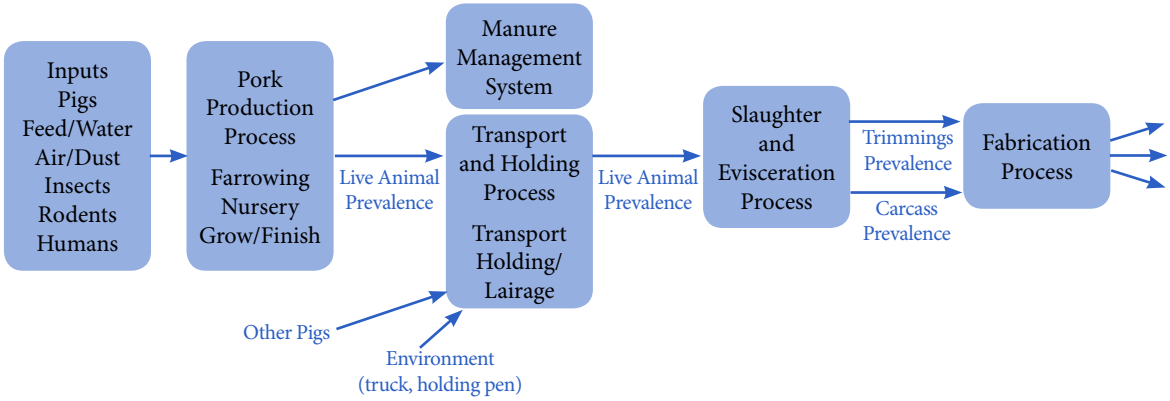
Authors: J.S. Dickson and H.S. Hurd, Iowa State University, Ames, IA; M.H. Rostagno, USDA, West Lafayette, IN.

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, serve as inputs to the next process. This figure suggests 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 in Swine

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

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



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more common than the clinical disease. In fact, asymptomatic intestinal carriage and fecal shedding of *Salmonella* represents a very common scenario in swine herds around the world. Although only about 5-10% of pigs will be shedding *Salmonella* at any given time, virtually every farm has or will soon have infected pigs carrying the bacteria in their gastrointestinal tract (Hurd et al., 2004; Garcia-Feliz et al., 2007; Farzan et al., 2008; Visscher et al., 2011; Rasschaert et al., 2012).

Transmission of *Salmonella* between hosts occurs mainly via the fecal-oral route of exposure (Fedorka-Cray et al., 2000; Griffith et al., 2006). However, aerosol experiments in swine, chickens, turkeys, and mice have shown that infections with *Salmonella* can be regularly achieved via this route (Clemmer et al.,1960; Darlow et al.,1961; Fedorka-Cray et al., 1995; Harbaugh et al., 2006; Oliveira et al., 2007), indicating that the traditional paradigm of fecal-oral transmission is not totally inclusive. Transmission studies exposing pigs to *Salmonella*-contaminated environments have shown that low numbers of the bacteria (10^2 – 10^3 colony-forming units or CFUs) are sufficient to infect the exposed animals (Fedorka-Cray et al., 1994; Hurd et al., 2001; Boughton et al., 2007). Fedorka-Cray et al. (1994) demonstrated that pigs infected with only 10^4 CFUs of *Salmonella* Typhimurium develop a short-term carrier state, whereas Gray et al. (1995) demonstrated that a dose of 10^8 CFUs 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 10^8 to 10^{10} CFUs (Wilcock and Olander, 1978; Wood et al., 1989; Nielsen et al., 1995). Rostagno et al. (2011) demonstrated that finishing pigs can carry in the intestinal tract and associated lymph nodes, and excrete high numbers of *Salmonella* Typhimurium in feces continuously for up to 4 weeks post-infection without any clinical symptoms. However, it has been shown that both infectious dose, and serovar are important determining factors for establishing the infection, and the amount and pattern (continuous or intermittent) of bacteria shedding (Gray et al., 1996; Loynachan et al., 2004; Osterberg and Wallgren, 2008; Osterberg et al., 2009).

Introduction and Dissemination of *Salmonella* in Swine Herds

Although pork contamination occurs in the abattoir, along the harvest and processing line, incoming pigs carrying *Salmonella* in their intestinal tract are determinants of the risk of contamination of carcasses and pork products. When an intestinal tract carrying *Salmonella* is lacerated, the whole carcass, as well as neighboring carcasses and equipments, is exposed to the contamination. Therefore, it is very important to understand the dynamic of *Salmonella* within swine herds supplying the abattoirs.

Infected pigs constitute 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 to other pigs in the same pen or even in the same room or building (Wood, 1989; Fedorka-Cray et al., 1994; Hurd et al., 2001; Barber 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. Lo Fo Wong et al. (2004) reported that pigs in herds with multiple suppliers had higher odds of becoming seropositive for *Salmonella* compared to pigs in herds that bred their own replacement stocks or with lower number of suppliers. Also, Zheng et al. (2007) reported that the proportion of seropositive pigs in the herds was associated to the risk of introducing *Salmonella* in the herds by purchase and transport of growing pigs, while integrated herds were less likely to become infected. Apparently, infection from breeding farms appears to be very important. 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 (Griffith et al., 2006). Rodent fecal samples have been shown to contain up to 10^5 CFUs of *Salmonella* (Henzler and Opitz, 1992). During an investigation of *Salmonella* contamination, which involved 23 pig farms, Davies and Wray (1996) 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. It has been also shown that 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, and much anecdotal evidence exists of cockroaches being a health risk and a vehicle for the spread of infectious organisms, including *Salmonella* (Bennett, 1993). However, cockroaches are only one part of the insect flora of domestic and rural environments. Beetles (lesser mealworm) are also frequently found in farms, and investigations have shown that they are important reservoirs for *Salmonella* (McAllister et al., 1994; Roche et al., 2009).

Animal feed is a recognized potential source of pathogenic microorganisms for farm livestock, including *Salmonella* (Davies et al., 2004; Molla et al., 2010; Binter et al., 2011). Major sources of *Salmonella* contamination of feed and feed materials include contaminated ingredients, infected animal vectors and contamination of the processing equipment and environment.

Data on prevalence of *Salmonella* in different parts of the feed chain are difficult to determine due to many confounders and variation sources. In the U.S., 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). Although feed containing ingredients of animal origin is a potential source of *Salmonella* infection to herds, it should be emphasized that ingredients of vegetable origin can also be a source of *Salmonella*-contaminated feed. For instance, a FDA 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). In the E.U., Wierup & Haggblom (2010) reported a *Salmonella* prevalence of 14.6% in soybean meal.

Water is not as likely a source of infection unless surface water is used for consumption or pigs have access to recycled lagoon water. 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 bacteria to effectively colonize water pipe lines in the farms, constituting a potential source of maintenance and dissemination of *Salmonella*.

Wild birds are recognized as carriers of *Salmonella*, and there is evidence suggesting their role in the transmission to swine (Barber et al., 2002; Andres et al., 2012). However, the *Salmonella*-contaminated environment is also a source of infections among wild birds, with the bacteria 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 (such as carcass disposal, insect control, manure storage, etc.) may contribute to the dissemination and maintenance of *Salmonella* within herds (Sandvang et al., 2000; Baloda et al., 2001; Callaway et al., 2005; Wells and Varel, 2008). *Salmonella* may persist in the environment for long periods, and cleaning and disinfection routines procedures may not always be efficient in eliminating the contamination. Bacteria 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 (Boyen et al., 2008; Rajtak et al., 2012). The temperature range for growth of *Salmonella* is between 5.5 and 45°C (42 and 113° F) (Doyle and Mazzotta, 2000). Modern intensive livestock production has created challenges for excreta/manure 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 (Rajtak et al., 2012). Gray and Fedorka-Cray (2001) found that *Salmonella* Choleraesuis survives in dry feces for at least 13 months post-shedding, demonstrating the importance of cleaning organic matter from the environment. Davies and Wray (1996) found high levels of *Salmonella* persisting in pig pens after disinfection. Gebreyes et al. (2006) detected *Salmonella* in floor swabs from barns after cleaning and disinfection, and before pig placement. In some of the studied cases, finisher pigs shed a *Salmonella* serotype that had been found in the floor swabs collected prior to their placement.

In three persistently infected herds, Dahl et al. (1997) studied the effects of moving young 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 harvest 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* up to six weeks of age, by removing them 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 previously 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 transmitting pathogens among groups of pigs. They are believed to be another important risk factor for the introduction and dissemination of pathogens in swine herds (Friendship, 1992; Moore, 1992). Amass et al. (2000) conducted a study evaluating the efficacy 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.

Between the Farm and the abattoir: Effect of Transportation and Lairage

As previously discussed, pigs may become infected with *Salmonella* at any of the production stages on-farm with a variety of risk factors affecting the probability of infection. In fact, market pigs carrying *Salmonella* when leaving the farm constitute the original source of contamination in the abattoir. However, between the farm and the abattoir, a variety of additional factors can further increase the risk of *Salmonella* infection of live pigs, and consequently, the risk of contaminations along the harvest and processing line.

It has been shown that the proportion of pigs infected with *Salmonella* increases between the farm and the abattoir (Hurd et al., 2002; Beloeil et al., 2004; Gebreyes et al., 2004), revealing an effect of the pre-harvest process of transportation and lairage. Each one of these steps can per se be considered as multifactorial effectors that result in increased risk of *Salmonella* infection and contamination. Therefore, it is very

difficult to establish consistent correlations between *Salmonella* status on-farm and at the abattoir.

For instance, it has been shown that a significant increase of *Salmonella* prevalence occurs when the common practice of split marketing is applied (Rostagno et al., 2009). Also, presence of *Salmonella* in transportation trailers prior to loading pigs at the farm has been shown to be common by several studies (Rajkowski et al., 1998; Gebreyes et al., 2004; Mannion et al., 2008). Moreover, lairage pens have been shown to be a major source of *Salmonella* infection for pigs entering the abattoir, immediately prior to harvest and processing (Botteldoorn et al., 2003; Rostagno et al., 2003; Boughton et al., 2007; Dorr et al., 2009; De Busser et al., 2011).

Worth mentioning is the increasing evidence that stress can also affect food safety risk. During the process of being transported from the farm to the abattoir, pigs are exposed to many different stressors (Warriss, 2003; Averos et al., 2008). As a consequence, the proportion of pigs carrying and shedding *Salmonella*, as well as the levels of the bacteria in the intestinal tract may increase in response to these stressors (Rostagno, 2009).

In summary, it is clear that the premarketing process as a whole constitutes a critical factor determining the risk of pre-harvest *Salmonella* infections, as well as of harvest and processing contaminations. Common management practices, transportation conditions, environmental contamination (trailers and lairage pens), as well as commingling and length of time in lairage, all affect the *Salmonella* infection frequency and levels in groups of pigs entering the harvest and processing line.

Pre-Harvest Conclusion

It is clear that *Salmonella* is a complex multifactorial challenge. 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 entering the harvest and processing line. In the end, *Salmonella* contamination of pork and pork products contain bacteria originating from the farm, from the transportation trailer, and from the lairage pens. Diligence must be applied to prevent its introduction and reintroduction from a variety of sources, such as the ones described in this review. The presence of *Salmonella*, as well as its level, in all these sources must be continuously monitored to determine the need for interventions.

Once *Salmonella* is present in a production system (which is very common) efforts must be made to reduce its persistence, spread and proliferation. Unfortunately, eradication is mostly not feasible. Control efforts should be directed towards reducing the prevalence of *Salmonella* carriers that leave the production system and enter the harvest and processing line. However, other than general hygiene and disease prevention/ control principles, there is limited knowledge on specific interventions that consistently affect within herd prevalence. Once pigs leave the farm, efforts should be directed towards reducing *Salmonella* exposure and stress. Some stress is inevitable during transportation and lairage. Therefore, reduction of exposure levels in the trailer and lairage pens is more likely to effectively reduce prevalence. Also, commingling during transportation and lairage should be minimized. Interventions to reduce environmental loads in the trailers and lairage pens need to be developed and tested.

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* have not been reported as intrinsic bacteria in the muscle tissue of healthy animals, so the assumption for the following discussion will be that *Salmonella* which 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 which carried *Salmonella* were three to four times more likely to test positive for *Salmonella* than were carcasses from animals which did not harbor *Salmonella*.

As a cautionary note, the reported incidence levels of *Salmonella* in pork products are profoundly influenced by the experimental design, the sampling methods and the sensitivity of the detection method. Because of this, not all reports may be directly comparable. As an example, it is common in North America to use sponge swab sampling for carcasses, following the methods outlined by USDA-FSIS (1996c). However, sponge sampling may recover fewer bacteria than excision samples (Gill et al., 2005; Palumbo et al., 1999), a potential issue acknowledged by USDA-FSIS (2011). However, sponge swab is non-destructive, and presents fewer technical challenges during the sampling process, and so is widely used. To increase the sensitivity of the sponge swab sampling method, it has been suggested that a larger surface area than that described in the USDA-FSIS method be swabbed (Linblad, 2007; Ghafir and Daube, 2008).

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 pre-harvest contamination, as previously discussed in this review. 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 is 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 non-inoculated 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 20 parts per million 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. A classic study by Jensen and Hess (1941) evaluated the process of sticking, and suggested that bacteria could enter the blood stream during the sticking. Their 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 which 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 blood stream 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 blood stream 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, 100 kilogram hog presented for slaughter, the blood volume is approximately 6 liters (Swenson 1975). 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 wound 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° C – 61° C (136° F – 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 (D_{10} 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 *Salmonella* generally decline. As an example, *Salmonella enterica* var. Typhimurium has a reported D_{10} 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 $\log_{10}$ cycle (9 D) reduction of *Salmonella*. This suggests that cross-contamination with *Salmonella* between carcasses in the scald tank would be an unlikely event.

However, other data suggests that scald tanks may harbor viable *Salmonella* and may be a potential source of cross contamination (Arguello et al., 2012; Botteldoorn et al., 2003). 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 that used a scald time which 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 which 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, de-hairing 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 bacteria survived the scalding operation and was 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 which 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). Other studies (Davies et al., 1999; Pearce et al., 2004) reported an increase in the incidence of *Salmonella* positive carcasses after mechanical dehairing, when compared to similar carcasses immediately after scalding. In a similar study, Nerbrink and Broch (1989) reported increases in *Enterobacteriaceae* populations on hog carcasses after de-hairing. However, the previously cited study also reported 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 al.;. (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* (Wood et al., 1989). 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 (Fedorka-Cray et al., 1995). 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 which has the greatest potential for *Salmonella* contamination (Alban and Stark,

2005; Arguello et al., 2012). In fact, some estimate that a significant portion of the carcass contamination occurs as a result of this step in the process (Berends et al., 1997). Damage which occurs 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 (USDA-FSIS,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 generally viewed 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 which 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 $\log_{10}$ cycles on beef carcasses. Reagan et al. (1996) reported that trimming reduced the total aerobic populations on beef carcasses by approximately 1.3 $\log_{10}$ 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 antimicrobial 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; Eggenberger-Solorzano et al., 2002) 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 antimicrobial effects on the surface microflora 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 which may be missed by visual inspection of the carcass.

An issue which may be important to the swine industry is the presence of *Salmonella* in lymph nodes. The lymph nodes in the head area have already been discussed, but there are lymph nodes throughout the carcass. Research with experimentally infected swine (Wood and Rose, 1992), other research with production pigs (Nollett et al., 2005) and current research with beef cattle (Brichta-Harhay et al., 2012) suggests that this may be a poorly understood mechanism for *Salmonella* contamination of fresh pork.

The USDA – FSIS generic HACCP plan for pork slaughter (USDA-FSIS,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 study by Borch et al. 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 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 which sprays cold water on the carcasses. The principle 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 25 grams 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 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 reduction 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 antimicrobial 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 was 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 effects 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* Typhimurium 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 and other personal equipment (Peel and Simmons, 1978; Berends et al., 1997). 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 (Arguello et al., 2012; Botteldoorn et al., 2003). 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. A study 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).

Harvest Conclusion

Salmonella contamination of fresh pork is influenced by many factors, beginning on the farm and continuing through fabrication. Although processing interventions may be more cost effective in controlling *Salmonella* (Goldbach and Alban, 2006), all parts of the system must use the best available practices to reduce the potential risk to consumers. If the focus is exclusively on processing, there is the potential that the incoming level of *Salmonella* in the live animal may simply overwhelm the interventions in place in the processing establishment. Likewise, careless processing and lack of adherence to good manufacturing practices may lead to high levels of *Salmonella*, even in the meat from animals which have been managed well on the farm. The production and processing of animal proteins must be viewed as a complete system, and not as individual components, if the overall goal is to produce meat with the lowest possible risk to the consumer.

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