FSIS Guideline to Control *Salmonella* in Swine Slaughter and Pork Processing Establishments

June 2023

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This guideline contains information and recommendations for pork producers to control *Salmonella* in market hogs from pre-harvest through slaughter. In particular, the guideline covers:

- Pre-harvest controls, including farm rearing, multi-hurdle interventions, transport, and lairage;
- Slaughter controls; and
- Pork fabrication controls, including processing, packaging, and distribution controls for pork cuts and comminuted pork products.

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Preface

This is a revised version of the *FSIS Compliance Guideline for Controlling Salmonella in Market Hogs.* The guideline has been updated in response to comments on previous versions and revised based on up-to-date science. The guideline also includes changes to improve its readability and has been renamed, *FSIS Guideline to Control Salmonella in Swine Slaughter and Pork Processing Establishments.*

This guideline represents FSIS' current thinking on the control of *Salmonella* in swine slaughter and pork processing and should be considered usable as of this issuance. The information in this guideline is provided to assist swine slaughter establishments in meeting the regulatory requirements. The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. This document is intended only to provide clarity to industry regarding existing requirements under the regulations. Under the regulations, swine slaughter establishments may choose to implement different procedures than those outlined in this guideline, and they would need to validate and support how those procedures are effective.

This guideline is focused on small and very small establishments in support of the Small Business Administration's initiative to provide small businesses with compliance assistance under the Small Business Regulatory Enforcement Fairness Act. However, all swine slaughter establishments may apply the recommendations in this guideline. It is important that small and very small establishments have access to a full range of scientific and technical support, and the assistance needed to establish safe and effective Hazard Analysis and Critical Control Point (HACCP) systems. Although large establishments can benefit from the information, focusing the guideline on the needs of small and very small establishments provides them with assistance that may be otherwise unavailable to them.

Purpose

This guideline contains information to assist swine slaughter establishments to safely slaughter swine and process raw pork products to meet FSIS regulations. The document discusses **best practice recommendations** by FSIS, based on the best scientific and practical considerations, and is derived from scientific literature. Establishments should select best practice recommendations that work for the unique in-plant conditions, equipment, and processes. Establishments may choose to adopt different procedures than those outlined in the guideline, and would need to support that those procedures are effective to meet validation requirements and support decisions in the hazard analysis (9 CFR 417.4(a)(1) and 9 CFR 417.5(a)(1)).

Establishments can always seek guidance from state university extension service specialists and HACCP Contacts and Coordinators to develop programs and plans not provided in this guideline to comply with HACCP regulatory requirements.

Reason for Reissuing the Guideline

FSIS is updating and reissuing this guideline to provide and reference the latest scientific support and new technologies available. These updates are part of FSIS' continuing efforts to improve the effectiveness of guidelines and recommendations to industry. Information related to multi-hurdle strategies, on-farm and pre-harvest controls, slaughter processing controls, interventions, lymph node removal, and post-processing and packaging interventions have been included. Controls regarding the production of pork cuts and comminuted pork products have also been added to this guideline.

Changes from the Previous Version of the Guideline

This guideline, dated June 1, 2023, is final. FSIS will update this guideline, as necessary, should new information become available.

FSIS made the following changes to this guideline to address the comments received on the previous version during the comment period and to include additional scientific information.

This version incorporates the following changes:

- Removed the word "compliance" from the document title and throughout the document to clarify that this document does not constitute regulatory requirements;

- Added relevant, current, peer-reviewed science related to swine slaughter, processing of pork cuts and comminuted pork products;

- Updated the pre-harvest interventions to include vaccine and bacteriophage interventions, housing and biosecurity, and water and feed management;

- Included pork products outbreak history;

- Included FSIS data collection and FSIS pork sampling information;

- Added information regarding hot shipping best practices;

- Added a lymph node removal best practices section; and

- Removed language related to the *Trichina* guidance, new technologies guidance, and validation guidance information because FSIS has separate guidance for these topics.

How to Effectively Use the Guideline

This guideline is organized to provide users with the current science and recommendations. To use this guideline, FSIS recommends that readers use the navigation headings to move efficiently through the document sections of interest. Hyperlinks, where provided, will quickly take you to the correct place in the document electronically and are also provided to other complementary documents.

The reference list at the end of the document provides resource material used in the development and revision of this guidance (References).

Questions Regarding Topics in this Guideline

If, after reading this guideline, you still have questions, FSIS recommends searching the publicly posted Knowledge Articles ("Public Q&As") in the askFSIS database. If, after searching the database, you still have questions, refer them to the Office of Policy and Program Development (OPPD) Risk Management and Innovations Staff (RMIS) through askFSIS and select "**Sampling**" or refer them by telephone at 1-800-233-3935.

Documenting these questions helps FSIS improve and refine present and future versions of the guideline and associated issuances.

FSIS Guideline to Control *Salmonella* in Swine Slaughter and Pork Processing Establishments

Background

Pathogens are a common cause of foodborne illness and may be present in live animals and in raw food. Swine have been identified as reservoirs for pathogens. Pathogen contamination can be transferred to pork products during slaughter, handling, and processing through improper handling and poor sanitary dressing procedures. FSIS recommends establishments use a variety of controls to prevent, reduce, or eliminate pathogens in pork products.

While this guidance addresses market hog production and *Salmonella*, the general concepts of sanitary dressing, antimicrobial intervention use, and process control assessment and verification can apply to the slaughter and production of other swine classes. Improvements in sanitary dressing and other process controls can reduce the levels of *Salmonella* and other enteric bacteria.

Public Health Relevance

Salmonella is a Gram-negative genus in the *Enterobacteriaceae* family and can multiply over a range of temperatures from 5°C/41°F to 45°C/113°F and a pH range of 4 to 9 (Doyle and Cliver, 1990). Nontyphoidal *Salmonella* is a common cause of bacterial foodborne illness, accounting for 11 percent of foodborne illnesses (about 1 million illnesses), 35 percent of foodborne-related hospitalizations, and 28 percent of foodborne-related deaths yearly.

Outbreaks resulting in human foodborne *Salmonella* illnesses associated with pork have been consistently reported on an annual basis, identifying pork as a vehicle for salmonellosis. During 1998–2015, there were 288 outbreaks attributed to pork, resulting in 6,372 illnesses, 443 hospitalizations, and four deaths (Self *et al.*, 2017). Salmonellosis symptoms can include diarrhea, fever, and abdominal cramps for 5–7 days after consumption. For older people, pregnant women, young children, and people with suppressed immune systems, salmonellosis can require hospitalization and can result in death.

KEY DEFINITIONS

Market hogs are healthy, young, uniformly-sized animals that are approximately 280 pounds and 6 months of age at slaughter.

Sanitary dressing is defined as the practice of handling carcasses and parts by establishment employees and machinery, throughout the slaughter process, in a manner that produces a clean, safe, and wholesome meat food product in a sanitary environment.

As shown in Table 1, during 2014–2019, 36 outbreaks (totaling 1,241 reported illnesses) averaging 207 illness each year have been associated with pork (CDC National Outbreak Reporting System (NORS), https://www.cdc.gov/nors/data/dashboard/index.html, 2014–2019). These estimates were calculated for outbreaks where pork was the sole identified food vehicle or identified as the sole contaminated ingredient. Table 1 shows that many foodborne illness outbreaks resulted from cooked pork products. Therefore, the level of *Salmonella* contamination in raw finished pork products may impact the number of foodborne illness outbreaks and establishments should consider measures to reduce *Salmonella* throughout slaughter and processing. Among the 6 years of data, 2015 had the most salmonellosis cases associated with pork consumption at 615 illnesses. For additional information please visit the Centers for Disease Control and Prevention (CDC) foodborne illness outbreak website at: https://www.cdc.gov/foodsafety/outbreaks/index.html.

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Table 1. *Salmonella* Foodborne Illness Outbreak History in Pork Products, 2014–2019

Products Affected	Year	Disease-Causing Organism	Case-Patients; States
Pork	2014	*Salmonella* Infantis	10; Conn.
Roasted Pork	2014	*Salmonella* I 4,[5],12:i:-	18; Ohio
Roasted Pork	2014	*Salmonella* I 4,[5],12:i:-	20; N.D.
Carnitas	2014	*Salmonella* Braenderup	8; Ill.
Blood Sausage	2014	*Salmonella* Uganda	12; Calif.
Pork	2014	*Salmonella* Agona	5; Calif.
Carnitas	2015	*Salmonella* I 4,[5],12:i:-	73; Wisc.
Pork	2015	*Salmonella* Agona	10; Minn.
Pork	2015	*Salmonella* I 4,[5],12:i:-	3; Ore.
BBQ Pork	2015	*Salmonella* Typhimurium	283; N.C.; 1 death
Pork	2015	*Salmonella* Typhimurium	17; Ill.
Roasted Pork	2015	*Salmonella* Typhimurium	20; R.I.
Carnitas	2015	*Salmonella* Mbandaka	17; Ga.
Pork	2015	*Salmonella* I 4,[5],12:i:-	192; Alaska, Calif., Idaho, Ore., Wash.
Pork	2016	*Salmonella* I 4,[5],12:i:-	2; Kansas
Pork	2016	*Salmonella* I 4,[5],12:i:-	6; Wisc.

Smoked Whole Hog	2016	*Salmonella* Newport	20; N.H.
BBQ Pork	2016	*Salmonella* Javiana	41; Ga.
Whole hogs, pork products	2016	*Salmonella* Goldcoast	12; Multistate
Roasted Pork	2016	*Salmonella* I 4,[5],12:i:-	15; Wash.
Pulled Pork	2017	*Salmonella* Typhimurium	10; N.Y.
BBQ Pork	2017	*Salmonella* Newport	7; S.C.
Pork Burrito	2017	*Salmonella* Typhimurium	6; Wisc.
Pork Rib Tips	2017	*Salmonella* Schwarzengrund	30; Ill.; 1 death
Whole Hog	2017	*Salmonella* Subspecies I	4; Wash.
Whole Hog	2017	*Salmonella* Subspecies I	5, Wash.
Pulled Pork	2018	*Salmonella* Typhimurium	109; Penn.
Pulled Pork	2018	*Salmonella* Typhimurium	35; Wisc.
Pulled Pork	2018	*Salmonella* I 4,[5],12:i:-	24; Tenn.
Pork	2018	*Salmonella* Eastbourne	21; Multistate
Pork	2018	*Salmonella* I 4,[5],12:i:-	18; Multistate
Pork	2018	*Salmonella* Adelaide	19; Multistate
BBQ Pork	2018	*Salmonella* I 4,[5],12:i:-	25; Tenn.
Pork	2018	*Salmonella* Adelaide	29; Multistate
Carnitas	2019	*Salmonella* Infantis	85; Ill.
Pork	2019	*Salmonella* Berta	30; Multistate

Salmonella outbreaks linked to human illnesses can have devastating effects on establishments that slaughter or process contaminated pork. For example, one case involving human salmonellosis linked to pork consumption resulted in an establishment voluntarily suspending operations and, ultimately, requesting to have its Grant of Inspection rescinded. Further information may be found at *Salmonella enterica* serotype I 4,[5],12:i:- Illness Outbreaks Associated with Pork Products, 2015-2016 (usda.gov).

Science-Based Food Safety Systems

FSIS published a final rule on Pathogen Reduction (PR); Hazard Analysis and Critical Control Point (HACCP) Systems in 1996. The final rule required that meat and poultry establishments under federal inspection take responsibility for preventing and reducing physical, chemical, and biological hazards throughout the food production process by implementing a system of science-based preventive controls, known as HACCP. Establishments must have an effective HACCP food safety system to comply with regulatory requirements with a focus on controlling hazards to prevent the adulteration of product.

Policy Background Information

Under the 1996 PR/HACCP rule, FSIS established food safety performance standards for pathogens on raw meat and poultry to provide incentives for industry to improve food safety and accountability measures. *Salmonella* performance standards for several raw product classes, including market hogs, were established to verify that establishments control food safety hazards. FSIS verifies performance standards by conducting the *Salmonella* verification testing program, in which FSIS samples and analyzes certain products for *Salmonella.*

From August 2010 to August 2011, FSIS conducted the nationwide microbiological baseline study in market hogs (The Nationwide Microbiological Baseline Data Collection Program: Market Hogs Survey August 2010 – August 2011). FSIS designed and performed this survey to estimate the percent positive and levels of microbiological pathogens and indicator bacteria (*e.g.*, *Salmonella*, generic *Escherichia coli* (*E. coli*), *Enterobacteriaceae* (EB), total coliforms, and Aerobic Plate Count (APC)) on market hog carcasses as indicators of process control. During the survey, FSIS collected sponge samples at pre-evisceration and post-chill from the belly, ham, and jowl portions of market hogs slaughtered in federal establishments across two operational shifts. FSIS collected a total of 3,920 sponge samples (1,960 at pre-evisceration and 1,960 at post-chill) at 152 establishments. Only market hogs were eligible for testing in the survey. Boar or stag swine, feral swine, roaster swine, and sows were excluded from the survey.

Results showed the positive pathogen rate was so low that the potential public health benefit did not justify any further expenditure of Agency resources. Thus, in late fiscal year 2011, FSIS discontinued sampling market hog carcasses under the *Salmonella* performance standards.

In 2015, FSIS began the Raw Pork Products Exploratory Sampling Program (RPPESP; 80 FR 3942) to collect data on the presence of *Salmonella*, other pathogens, and indicator organisms in pork products. RPPESP included multiple phases from 2015 to 2021, and continues while data is being analyzed to make decisions on future raw pork products sampling.

During the initial phase of the sampling program, FSIS laboratories analyzed approximately 1,200 samples and evaluated the sampling results. FSIS continued to collect and analyze raw pork products for *Salmonella* while designing the second phase of the study. FSIS analyses determined the national prevalence of *Salmonella* in raw pork products, highlighting the need for additional pathogen reduction strategies for these products. *Salmonella* prevalence was highest in comminuted products (28.9%), followed by intact (5.3%), and non-intact (3.9%) cuts (Scott *et al.*, 2020). FSIS will continue to use these data to inform food safety policies for pork products.

FSIS published a Final Rule for the Modernization of Swine Slaughter Inspection (84 FR 52300) in 2019, which specified that all swine slaughter establishments must develop, implement, and maintain in their HACCP plans written procedures to prevent the contamination of carcasses and parts by enteric pathogens, fecal material, ingesta, and milk. In addition, the rule requires establishments to verify that they are addressing enteric pathogens by testing at both pre-evisceration and post-chill, or just at post-chill for small and low volume establishments. In addition, FSIS eliminated the codified *Salmonella* standards for swine carcasses from the regulations.

FSIS Guideline: Modernization of Swine Slaughter Inspection – Developing Microbiological Sampling Programs in Swine Slaughter Establishments. This guideline is designed to assist all swine slaughter establishments, regardless of swine class, to comply with new microbiological sampling and analysis requirements, including information on statistical process control, that apply to all official swine slaughter establishments as published in the final rule.

Multi-Hurdle Intervention Approach

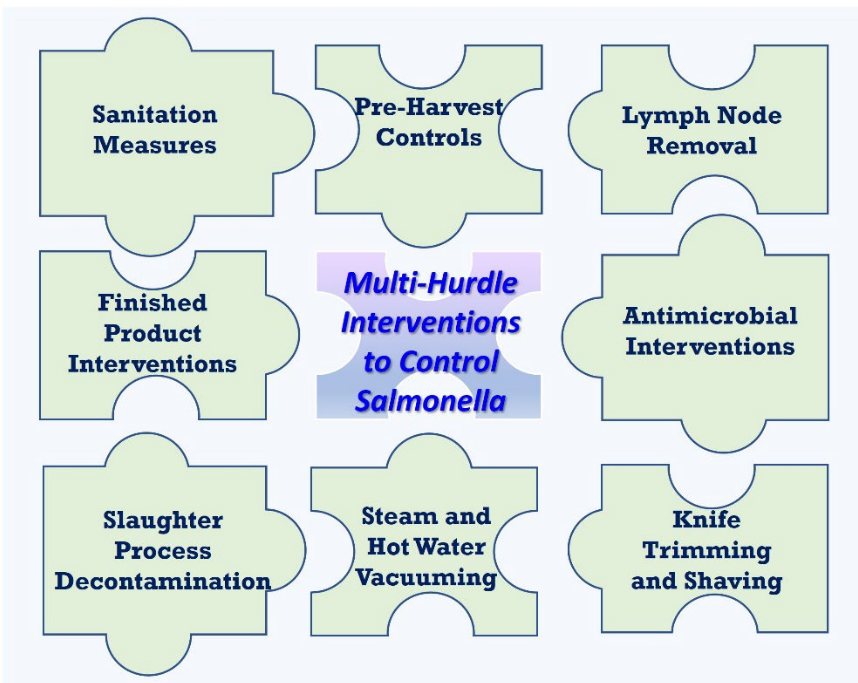
FSIS recommends that establishments slaughter and process swine in a manner designed to prevent, reduce, or eliminate contamination from occurring at every step of the process. A focus on sanitary dressing procedures and preventing contamination throughout the slaughter and dressing process is important for swine slaughter establishments to prevent and minimize the risk of *Salmonella* in their operation and finished products. FSIS also recommends establishments use decontamination and antimicrobial intervention treatments, as necessary, to address any contamination that may result from the slaughter process or that otherwise occurs on carcasses.

FSIS recommends that intervention and control strategies be formulated based on a combination of measures that are both practical and economically feasible. FSIS recommends a multi-hurdle approach of interventions and controls to reduce *Salmonella*. Using a multi-hurdle approach is key to reducing *Salmonella* in livestock on-farm, at slaughter, and in finished products (**Figure 1**). Multi-hurdle slaughter and processing interventions contribute to reducing *Salmonella* on pork carcasses and are more effective than single interventions alone (Young *et al.*, 2016). Such multi-hurdle combinations must be validated and verified by each establishment to account for the context and unique conditions at the establishment to meet the requirements of 9 CFR 417.4.

Salmonella prevalence in the herd is a significant factor for determining the *Salmonella* prevalence and levels on carcasses, as illustrated in Danish pork production (Alban and Stark, 2005). This study shows that multi-hurdle interventions are most effective at decreasing *Salmonella* prevalence on carcasses, including efficient singeing and reducing cross-contamination during polishing, evisceration, and handling. In addition, hot water decontamination is one of the most cost-effective interventions that establishments can use to control *Salmonella* (Goldbach and Alban, 2005).

FSIS recommends that regulated establishments focus on pre-harvest controls, effective sanitary dressing, and processing controls to prevent microbiological contamination and the creation of insanitary conditions. When an establishment makes changes to improve sanitary dressing, this affects process control and should result in raw pork products that have less contamination with pathogens, including *Salmonella*.

Figure 1. Multi-Hurdle Intervention Approach. There are many interventions and control strategies establishments can use that are both practical and economically feasible. Using a multi-hurdle approach is key to reducing *Salmonella* in livestock on-farm, on carcasses at slaughter, and in finished pork products. This figure shows some options that establishments may consider as part of their approach.



Pre-Harvest Controls

FSIS recommends establishments work closely and establish communication with their livestock suppliers to identify and address on-farm controls as means of targeting multiple areas of swine production through pre-harvest control of *Salmonella* coming into slaughter establishments. For small and very small establishments, initiating communications with farmers and transporters is the first step in understanding what pre-harvest controls may be available to incorporate to better control *Salmonella* before lairage.

Recommended Best Practices: Pre-Harvest Controls

- Control rodents, wild birds, and other pests in housing.
- Establish biosecurity measures.
- Control commingling of piglets in the nursery and reduce human contact.
- Practice good on-farm sanitation and dead control.
- Vaccinate herd for *Salmonella.*
- Manage diet as a *Salmonella* control measure.
- Wash and sanitize transport trucks after each load.

Control of *Salmonella* at the herd level is critical to prevent the spread on-farm, through hygienic processes, feed and water management, live animal transport, and lairage before hogs even reach the slaughter line (De Busser *et al.*, 2013). A Danish study, (Hurd *et al.*, 2008), measured the relationship between pig health and contamination, where overall pig health was assessed via lesions at slaughter such as the number of abscessed heads and peel-outs. This study concluded that for every percentage point increase in lesions there is a 4 to 5 percentage point increase in contamination. This strong association means that animal management decisions on the farm that impact pig health will directly impact public health. There is an association between *Salmonella*-positive hogs at pre-harvest and contaminated carcasses at the end of the slaughter line (Vieira-Pinto, 2006). Therefore, control of *Salmonella* prior to the livestock's arrival at the slaughterhouse is one of the most important controls that slaughter establishments can implement to reduce incoming *Salmonella* contamination.

One study found that carcass contamination was mainly influenced by the probability that at least one hog contributing to the pool was seropositive (Baptista *et al.*, 2010). This finding suggests the *Salmonella* carcass contamination came from the incoming hogs and that *Salmonella* control on the farm is an important control that establishments should consider in control programs. In a survey and analysis of 23 farms (San Roman *et al.*, 2017), a number of risk factors were identified that were associated with *Salmonella* shedding, including hogs that were:

- Below 233 pounds (106 kilograms) at final slaughter weight;
- From small farms with fewer than 1,800 hogs;
- Slaughtered in the fall season;
- From farms lacking rodent control programs;

- From farms lacking shower and changing rooms for employees; and
- Fed fine-floured feed instead of pellets.

Pre-harvest controls have been shown to be important practices to improve food safety (Bearson *et al.*, 2017). There are a number of pre-harvest controls and interventions that establishments should consider when developing pre-harvest management controls to address *Salmonella*. **Pre-harvest controls and interventions** provide the establishment an opportunity to reduce the spread of *Salmonella* and improve the condition and quality of hogs entering the slaughter environment. Small and very small establishments may not have access to or direct conversations with all farmers or suppliers and may not be able to implement all best practices listed in this document, but having awareness, initiating small changes, and identifying possible pre-harvest controls, when possible, is an important first step. This is especially important when an establishment identifies that *Salmonella* is trending upward in FSIS or establishment microbiological testing results. The establishment may see a loss of process control through their sanitary dress measures and records, overwhelmed antimicrobial interventions, or testing results. For example, in this situation, an establishment may decide to initiate a conversation with the live animal transport team to ensure trucks are washed and sanitized between each load brought to the establishment to reduce the amount of mud and dirt on incoming livestock. Additionally, an establishment may seek suppliers and farmers that are interested in a more holistic farm-to-fork approach to raise and produce pork products and, as a result, are willing to have pre-harvest conversations and share on-farm control information.

Pre-Harvest: Farm Rearing, Housing, and Biosecurity Measures

Control of *Salmonella* begins on the farm. Understanding and employing strategies that address the dissemination and persistence of *Salmonella* can lead to effective controls at pre-harvest. **Biosecurity** refers to the procedures used to decrease the chances of an infectious disease being introduced or transmitted onto a farm or facilty by people, animals, equipment, or vehicles. Biosecurity is an important measure that can help farms prevent the introduction and reduce the prevalence of *Salmonella* in swine (Food and Agriculture Organization of the United Nations, World Health Organization, 2016).

Salmonella, including strains that are resistant to antimicrobials, can persist in housing and readily pass between herds as live animals move through housing and slaughterhouses (Bridier *et al.*, 2019). Pest control for rodents and arthropods, such as cockroaches, can lower incidence of *Salmonella* contamination on farms (Andres-Barranco *et al.*, 2014). Incorporating measures to prevent bird concentrations around farm premises to help control *Salmonella* transmission to pigs (Andres-Barranco *et al.*, 2014). In addition, the presence of wild animal carcasses near farms has been found to correlate with isolates of *Salmonella* spp. in livestock (Rubini *et al.*, 2016). Thus, preventing the spread of infection through wildlife management is another important means of on-farm control (Skov *et al.*, 2008). Another study revealed a correlation on hog farms between having a high prevalence of *Salmonella* shedding from pigs and high *Salmonella* levels detected on pen floors, employee boots, and in insects (Barber *et al.*, 2002).

KEY DEFINITIONS

Biosecurity measures are the procedures a producer and processor can take to protect animals and humans by preventing the introduction and reducing transmission of diseases or harmful biological agents.

Pre-harvest controls and interventions include many practices and measures, discussed in this guidance, that provide the establishment an opportunity to reduce the spread of *Salmonella* and improve the condition and quality of hogs entering the slaughter environment.

Pre-Harvest: Water and Feed Management

FSIS recommends establishments consider the diet as an important intervention strategy to control *Salmonella* in hogs. Feed management and acidification of feed or water using organic acids are other pre-harvest controls that can be effective to control the spread of *Salmonella* on the farm (Food and Agriculture Organization of the United Nations, World Health Organization, 2016). Understanding and controlling gut health helps to increase disease resistance against *Salmonella* in hogs (Argüello *et al.*, 2019). Research shows some feed supplements, including calcium-butyrate and probiotics, such as *Lactobacillus, Bacillus licheniforms*, and *Bacillus subtilis* can have measurable effects against *Salmonella* on the farm. Effects of these different feed supplements include decreased shedding of multiple *Salmonella* species and protection of newly weaned piglets from disease (De Ridder *et al.*, 2013, Liu *et al.*, 2019, Barba-Vidal *et al.*, 2017). Other studies show some supplements, like yeast cell wall, have no measurable effect on *Salmonella* (Burdick Sanchez *et al.*, 2019).

Salmonella shedding in sows is associated with the gut bacteria (microbiota) in piglets, particularly at the end of gestation (Lariviere-Gauthier *et al.*, 2017). Analysis of the relationship between sows and piglets showed that piglets play an active role in *Salmonella* contamination on farms. Decreasing sow shedding through diet control and increasing colostrum intake helps to control *Salmonella* prevalence in piglets. (Casanova-Higes *et al.*, 2019).

Further, FSIS recommends establishments evaluate and consider the environmental and microbiological quality of water. In a 2003 analysis, 33.3% of hog drinking water samples were found to be contaminated with *Salmonella* (Hurd *et al.*, 2003). Research indicates that organic acid additives to water have limited effectiveness unless added prior to *Salmonella* infection at the farm (Arguello *et al.*, 2013; De Busser *et al.*, 2013). Probiotics (direct-fed microbials) added to water can reduce fecal shedding and, therefore, prevent further spread of *Salmonella*; however, this additive does not remove *Salmonella* harborage within the individual hog (Walsh *et al.*, 2012).

Pre-Harvest: Vaccine and Bacteriophage Interventions

Salmonella is widespread in swine production. Vaccination is an important measure that swine producers can use to control *Salmonella* presence in herds. One challenge for producers is to understand the diversity of *Salmonella* serotypes in production to identify the most effective vaccination strategy. Research suggests that vaccination can be used to control clinical disease while also reducing *Salmonella* shedding in herds. As stated above, FSIS recommends slaughter establishments develop relationships and open communication with livestock suppliers to establish measures that reduce infection and shedding in incoming herds.

Research shows that vaccination with an attenuated vaccine decreased *Salmonella* Typhimurium transmission in pigs (De Ridder *et al.*, 2013). After *S*. Typhimurium experimental infection or after vaccination with an *S.* Typhimurium-based inactivated vaccine, different porcine antibodies were produced, and infected and vaccinated pigs were able to be distinguished (Gebauer *et al.*, 2016). The combination of an attenuated *S.* Typhimurium vaccine and boosting with an inactivated *S.* Choleraesius vaccine was more effective in limiting infection from *S.* Choleraesius than using the *S.* Choleraesius inactivated vaccine alone (Alborali *et al.*, 2017). An attenuated *S.* Typhimurium vaccine protects against systematic disease due to *S*. Choleraesuis and reduced shedding in the environment to limit transmission and enhance food safety (Bearson *et al.*, 2017). Another study found that vaccination of both sows and piglets, sows and fattening pigs, or piglets alone using an attenuated *S.* Typhimurium vaccine reduced *Salmonella* prevalence in slaughter pigs, but not until the second production cycle (Peeters *et al.*, 2020).

Several laboratory studies also show promising results that continue to advance vaccination programs. While it has not yet progressed to testing in swine, a live attenuated *Salmonella* Typhimurium vaccine in a mouse model was successful in protecting mice against lethal oral challenge with a *S*. Typhimurium virulent strain. In addition, the attenuated strain was easily eliminated from the environment because it was unable to form a biofilm and did not survive under desiccated conditions (Latasa *et al.*, 2016). Vaccination of mice with a live attenuated *Salmonella* Typhimurium mutant strain was effective against porcine proliferative enteropathy caused by *Lawsonia interacellularis* and salmonellosis, giving dual protection (Park *et al.*, 2019). The advancement of vaccines for swine continues to improve as research expands and more producers are using vaccines to control *Salmonella* on-farm.

KEY DEFINITIONS

Log reduction is a mathematical term describing how effective a product is at reducing pathogens. A log reduction is a 90% reduction of a pathogen.

For example, a 2-log reduction is a 99% reduction of a pathogen and a 3-log reduction is a 99.9% reduction of a pathogen in a product. Log reduction of *Salmonella* and other enteric bacteria are important measures of process control.

Bacteriophages (or 'phage') are viruses that can infect and kill bacteria, such as *Salmonella*. Bacteriophages are self-replicating and self-limiting because they only multiply when bacteria are available. Bacteriophages are also specific to a species or strain of bacteria to accurately target a single bacterial population, are commercially available, and many are generally recognized as safe (GRAS). For more information on GRAS status, please refer to the USDA Animal and Plant Health Inspection Service Center for Veterinary Biologics, the FDA GRAS Notification Program, and FSIS Directive 7120.1. These phages readily reduce bacterial levels in food products and surfaces, and can enhance a multi-hurdle approach to improve *Salmonella* control and food safety (Moye *et al.*, 2018). As a result, these features make bacteriophages a very useful intervention to target *Salmonella* in swine. A bacteriophage can be distributed to live swine by injection or through feed and water supplements. Most bacteriophage applications result in 1–3 **log reduction** in bacteria, which gives significant health and food safety benefits (Moye, *et. al*., 2018).

Bacteriophages effectively controlled *Salmonella* in a pig challenge model and may be an alternative to antibiotics (Seo *et al.*, 2018); however, this is an ongoing area of research and development. Currently, there is limited evidence that bacteriophage is effective in commercial applications. In third generation cephalosporin-resistant *Salmonella* isolates, the P1 family bacteriophage aided in detection and spread of antimicrobial resistance in pathogens (Yang *et al.*, 2018).

Phage cocktails, which are combinations of multiple phages in a single dose where each phage targets a different pathogen, can be used to control various foodborne pathogens in foods. Reporter phage systems, where a phage is "genetically reprogrammed" to express an easily detected substance, have been developed for specific detection of pathogens in foods (Bai *et al.*, 2016). A bacteriophage cocktail when administered to young, *Salmonella* Typhimurium-infected pigs reduced *Salmonella* colonization 2- to 3-logs (99%) in the tonsils, ileum, and cecum. The cocktail was also effectively microencapsulated for feed or water delivery (Wall *et al.*, 2010). Bacteriophage treatment reduced intestinal *Salmonella* Typhimurium in inoculated pigs compared to controls at necropsy (Callaway *et al.*, 2011).

In addition to being used to control *Salmonella* infection in live pigs, bacteriophages can be used in other ways, such as decontaminating food preparation surfaces (Woolston *et al.*, 2013) and eliminating *Salmonella* directly from food products. A cocktail of six bacteriophages targeting *Salmonella* was tested for its ability to reduce the levels of *Salmonella* on surfaces mimicking those commonly found in food processing establishments, such as stainless steel and glass. The bacteriophages significantly reduced (by approximately 2–4 logs) the population of susceptible *Salmonella* strains on all surfaces examined (Woolston *et al.*, 2013).

Pre-Harvest: Live Animal Transport

Stress during live animal transport to slaughter is known to influence the physiological and biochemical processes in hogs (Benjamin, 2005). Stress is thought to affect the bacterial ecology of the gastrointestinal tract and the immunity of the animal, resulting in increased *Salmonella enterica* shedding (Hurd *et al.*, 2003).

On-farm environmental factors play a significant role in spreading *Salmonella* (Funk *et al.*, 2001b), including increased shedding due to biosecurity and environmental factors (Funk *et al.*, 2001a). Rapid infection after exposure to *Salmonella* during transport (*e.g.*, when trailers are not cleaned between loads from different sources) is a major reason for increased *Salmonella* prevalence in hogs (Hurd *et al.*, 2002). Research shows increased serotype diversity of isolates obtained after slaughter compared to isolates from pen mates necropsied on the farm (Hurd *et al.*, 2005). This increase in diversity suggests that hogs may be exposed to new *Salmonella* sources after leaving the farm. FSIS does not recommend mixing hog herds during transportation (Boes *et al.*, 2001).

Research has shown that often overlooked areas in pig farms and slaughterhouses are harborage areas for *Salmonella*. *Salmonella* isolates increased on the pathways used by the live animal transportation trucks into the slaughterhouse with a prevalence of 56% before arrival increasing to 72% after departure (Henry *et al*., 2018). *Salmonella* was also found on truck mudguards, on truck cabin carpet, and the floors of trucks carrying pigs from nurseries to finisher barns. Therefore, cleaning and disinfection of the transport trucks is essential to avoid cross-contamination (Henry *et al.*, 2018; Dorr *et al.*, 2009). Washing and sanitizing transport trailers after each load of hogs significantly reduces *Salmonella* levels and reduces possible spread through contaminated trailers and bedding (Rajkowki *et al.*, 1998). FSIS recommends slaughter establishments maintain open communication with suppliers to ensure that cleaning and disinfection procedures are used to reduce *Salmonella* levels entering the slaughterhouse premises and creating harborage concerns at lairage.

Pre-Harvest: Lairage

Microbiological contamination in the slaughterhouse environment can start with the delivery of *Salmonella*-positive hogs. However, there is significant scientific evidence that many hogs are exposed to *Salmonella* during lairage. Lairage is defined as the accommodations provided for livestock being transported to or held at the establishment. It includes the unloading bays and ramps, drive alleys, and holding pens at the establishment. Awareness of potentially significant areas of contamination can serve as reinforcement to reduce *Salmonella* during harvest. Studies have also shown that improved pre-harvest sanitation can reduce the levels of *Salmonella* exposure. FSIS encourages further study and solutions by industry to control and reduce the spread of *Salmonella* in hog slaughter facilities with particular attention to controls at lairage.

Scientific studies indicate that lairage is a significant factor in the spread of *Salmonella.* Lairage contamination can lead to contamination of the pigs in feces, cecal contents, and mesenteric lymph nodes (Dorr *et al.*, 2009). A study of hog slaughter processing concluded that preventive measures at lairage are cost-effective measures an establishment can take to prevent cross-contamination that leads to rapid infection (Van der Gaag *et al.*, 2004). Prolonged transportation and holding in lairage may induce *Salmonella* shedding by infected hogs (Alban and Stark, 2005).

Several studies offer insight into the pre-harvest ecology of *Salmonella* during lairage (Hurd *et al.*, 2001a, b; Hurd *et al.*, 2002; Hurd *et al.*, 2003). These studies suggested the following:

- Hogs become internally contaminated with *Salmonella* (Hurd *et al.*, 2001a);

- Surface contamination of the holding pen reflects the quality of in-plant practices and may not be a useful measure of pre-harvest prevalence (Hurd *et al.*, 2001b); and

- There is rapid infection during holding, suggesting the holding pen is an important *Salmonella* control point in the pre-harvest pork production chain (Hurd *et al.*, 2003).

FSIS recommends that establishments use a variety of preventive measures at lairage to prevent and reduce the spread of *Salmonella* among and between incoming herds, including minimizing the time the hogs are held in lairage (Hurd, 2001b) and preventing overcrowding during time in lairage (Hurd, 2001a, b). Cleaning and disinfecting between batches of pigs has been shown to be effective in decreasing levels of *Salmonella* in pigs going to slaughter. However, FSIS recommends additional control measures be used because of a high prevalence of infection in subsequent pigs using the same holding pens, and the presence of rodents, which may contribute to carry-over of pathogens between batches of pigs (Martelli *et al.*, 2017). Establishments are required to provide fresh water in lairage pens to comply with humane handling requirements (9 CFR 313.2(e)). Best practices also include changing the water between herds to minimize cross-contamination, if not using automatic waterers (Rostagno *et al.*, 2003). Maintaining lairage pens in good condition is necessary to prevent injury to animals and comply with regulatory requirements of 9 CFR 313.1. It also allows the pens to be cleaned and sanitized to prevent harborage of microorganisms. Slatted, sloped, or elevated floors are important to reduce waste and water accumulation that can contribute to *Salmonella* spread. In addition, it is often most practical for establishments to clean and sanitize pens and alleyways when the structures are empty.

Segregating *Salmonella*-positive herds and processing them at the end of the production day is an important control measure to prevent the spread of *Salmonella* among herds (Alban and Stark, 2005; Berriman *et al.*, 2013; Boes *et al.*, 2001). Establishments should avoid mixing of herds during lairage (Borch, 1996; Alban and Stark, 2005). FSIS also recommends establishments disinfect lairage pens and alley ways between herds, using effective cleaners and sanitizers, such as chlorinated alkaline detergents, followed by disinfection with a quaternary ammonium solution (Dehalle *et al.*, 2008). There are numerous cleaners and sanitizers that establishments may choose to use and those decisions should be based on the unique characteristics of an establishment's food safety plan and available support. Slaughterhouses can have persistent colonization of *Salmonella,* including

KEY POINTS

Lairage Salmonella Control Measures

- Minimize the time the hogs are held in lairage.
- Prevent overcrowding during time in lairage.
- Keep water in lairage pens fresh and change after each herd.
- Use slatted, sloped, or elevated floors in lairage pens to reduce waste and water accumulation.
- Maintain lairage pens in good condition to prevent injury to animals.
- Avoid mixing of herds.
- Disinfect lairage pens and alley ways between herds, when practical, using effective cleaners and sanitizers.
- Ensure that hogs are washed clean and are dry enough to prevent dripping at the time of stunning.
- Segregate *Salmonella*-positive herds and process them at the end of the production day.

strains with antimicrobial resistance, as live animals move through the process. Cleaning and disinfection procedures can reduce the presence of *Salmonella* in lairage pens; however, intensive cleaning alone is not enough. When practical, allowing the cleaned and disinfected pens to dry before introducing animals into the lairage pens is more effective in reducing microbiological contamination levels (Boughton *et al.*, 2007). A multi-step process of using detergent to clean and a chlorocresol-based disinfectant to disinfect followed by 24–48 hours of drying was the most successful approach to remove *Salmonella* presence from lairage pens in one study (Walia *et al.*, 2017). Drying lairage pens by air drying or with heaters or other means can significantly aid in reducing *Salmonella* presence and its spread among herds moving through lairage pens. In another study, cleaning and disinfecting procedures at the slaughterhouse did not lead to changes in antimicrobial susceptibility, but these procedures did change which types of bacteria were able to persist in the slaughterhouse (Bridier *et al.*, 2019). Therefore, *Salmonella* control on-farm is important in addition to cleaning and disinfecting at lairage.

Pen showers are also important measures to ensure that hogs are washed clean, when appropriate. FSIS recommends establishments consider weather conditions and when it is appropriate to use pen showers because cold conditions and ice formation may create an animal welfare concern. The cleanliness of hogs entering the slaughterhouse affects the final microbiological status of the carcass; therefore, washing the animals before slaughter and other pre-harvest controls are important to reduce *Salmonella* throughout the process (Letellier *et al.*, 2009). In addition, FSIS recommends that the hogs should also be dry enough to prevent dripping at the time of stunning; if they are dripping, the moisture may contribute to cross-contamination during the slaughter process.

Airborne bacterial contamination has been shown to spread from lairage to the slaughter room, clean room, and into the chillers; therefore, FSIS recommends establishments take precautions to limit overspray and aerosolization through techniques and equipment (Kotula and Emswiler-Rose, 1988; Rahkio and Korkeala, 1997; Pearce *et al.*, 2006). Establishments should minimize airborne contamination by ensuring adequate ventilation and controlling the air flow in the establishment to separate the highly contaminated areas (*e.g.*, kill line) from areas with low levels of contamination (*e.g.*, cooler, final processing areas) (Bolton *et al.*, 2002b).

Measures taken at pre-harvest alone are not sufficient to reduce *Salmonella* on carcasses; FSIS recommends establishments also take slaughter controls to reduce prevalence on pork carcasses (Food and Agriculture Organization of the United Nations, World Health Organization, 2016).

Preventing Cross-Contamination Through Sanitary Dressing

Cross-contamination occurs when pathogens are carried throughout the establishment and adhere to carcasses, parts, and meat contact surfaces. Research shows that there can be airborne bacterial contamination at levels up to 3.5 $\log_{10}$ CFU/m^3 within the slaughter establishment (Bolton *et al.*, 2002b). Further, *Salmonella* can survive in aerosols at 24°C/75.2°F and 75% humidity for periods exceeding 24 hours (McDermid and Lever, 1996). These positive correlations within the environment suggests that contaminated air may be a source of carcass contamination. Establishments can address airborne contaminants by taking appropriate steps to reduce aerosolization of dirt at live animal receiving and holding, preventing partially dressed animals from coming into physical contact with one another and contaminated equipment and tools. Establishments can also limit the splashing of water and other liquids throughout the slaughter and dressing process.

Establishments should focus process controls on preventing contamination to comply with 9 CFR 310.18(c), which requires all establishments that slaughter swine to develop, implement, and maintain written procedures in their HACCP systems (HACCP plan, Sanitation Standard Operating Procedures, or prerequisite program) to prevent contamination of carcasses and parts by enteric pathogens, feces, ingesta, and milk throughout the entire slaughter and dressing operation. FSIS inspectors perform post-mortem inspection as described in FSIS Directive 6100.2, *Post-Mortem Livestock Inspection*. FSIS inspectors verify that establishments effectively prevent contamination of swine carcasses and parts throughout the slaughter and dressing operation as required in 9 CFR 310.18(c). FSIS inspectors also verify that establishments meet the recordkeeping requirements in 9 CFR 310.18(d) as described in FSIS Directive 6410.4, *Verifying Swine Slaughter Establishments Maintain Adequate Procedures for Preventing Contamination of Carcasses and Parts by Enteric Pathogens.* The requirements in 9 CFR 310.18(c) and (d) apply to all swine slaughter establishments as per the Final Rule for the Modernization of Swine Slaughter Inspection (84 FR 52300).

9 CFR 416.3 requires establishments to maintain equipment and utensils in sanitary condition so as not to adulterate product. FSIS recommends establishments use appropriate equipment and arrange equipment in a configuration designed to prevent cross-contamination of carcasses and parts. The establishment should use equipment

KEY POINTS

Prevent Cross-Contamination

- Minimize airborne contamination through effective ventilation and control of air flow.
- Sanitize equipment and tools.
- Enforce employee hand washing to prevent contamination during processing.
- Separate the processing areas and the facilities for hand washing, access to toilet facilities, and areas where clothes and footwear are changed.
- Use walls and other separating structures, between “dirty” and “clean” processes, to maximize spatial separation of activities.

designed so that it can be adequately cleaned and sanitized daily or as often as needed to prevent insanitary conditions. Establishments should ensure that functional lavatories are appropriately located, with hand washing and disinfection units strategically placed on the slaughter floor to meet the requirements of 9 CFR part 416.

Cross-contamination accounts for about 30% of swine carcass contamination (Botteldoorn *et al.*, 2003). Slaughter establishments can reduce pathogen prevalence by conducting operations in a manner that reduces contamination and cross-contamination events. For example, a study showed that stick knives and carcass splitting equipment tested positive for *Salmonella* and may be a source of cross-contamination (Botteldoorn *et al.*, 2003). Establishments can eliminate or reduce contamination through adequate separation of carcasses, parts, and viscera during dressing, routine cleaning and disinfection of equipment and hand tools. Good sanitary dressing practices generally prescribe that equipment should be disinfected between each carcass.

Sanitary maintenance of slaughterhouse equipment, good slaughtering practices, and effective washing and disinfection of equipment and materials at steps throughout the process are critical to reducing *Salmonella* contamination. If sanitary conditions are not maintained throughout slaughter and processing, the major reductions in microbiological load noted at some stages of the process can be offset by cross-contamination or recontamination at subsequent stages (Young *et al*., 2016).

Establishments should have procedures to address the main routes for cross-contamination, including:

- Airborne bacteria from physical or mechanical disruption;
- Contamination of walls or floors by splashing of contaminated fluid;
- Contact with dirty surfaces through equipment, hands, and clothes; and
- Contact between carcasses, parts, and viscera that lack adequate separation.

Introduction to the Slaughter Process

Consistent monitoring of establishment controls throughout slaughter, dressing, and fabrication is one way to determine if process control is achieved. Sampling is another way to assess effective process control. Appropriate modifications of establishment operations based on information provided in this guidance should reduce the levels of *Salmonella* in slaughter steps.

Salmonella presence on hog carcasses was tested at two large U.S. commercial pork processing plants with overall *Salmonella* prevalence on carcasses at pre-scald (91.2%), pre-evisceration (19.1%), and after chilling (3.7%) (Schmidt *et al.*, 2012). The contamination levels of *Enterobacteriaceae* and *Salmonella* spp. were studied after eight processing steps, including stunning, bleeding, scalding, singeing, polishing, evisceration, final inspection, and chilling. The results show that scalding and singeing led to decreases in total viable bacterial counts; in contrast, all other processing steps led to increases in total viable bacterial counts (Wheatley *et al.*, 2014). Microbiological contamination related to both food safety and spoilage show similar contamination patterns throughout slaughter, dressing, and processing steps in swine slaughter (Zwirzitz *et al.*, 2019). These studies support using a multi-hurdle approach to control *Salmonella* and that monitoring procedures at each step throughout the slaughter process are needed to assess the effectiveness of interventions. Each establishment should validate and verify the effectiveness of each intervention (9 CFR 417.4). For more information on validation, see FSIS' Guideline on HACCP Systems Validation.

FSIS has also provided guidance for establishments when designing HACCP plans as shown in the HACCP Model for New Swine Inspection System (NSIS).

KEY POINTS

Basic Sanitation Measures

- Maintain adequate sanitation in pens.
- Maintain adequate sanitary separation between each carcass on the rail, and between parts and viscera during dressing.
- Routinely clean and sanitize equipment and hand tools that are used to prepare the carcass for presentation prior to opening, and remove visual contamination after cutting into the carcass.
- Design and arrange equipment to prevent the contact of successive carcasses and carcass parts with contaminated equipment.
- Frequently wash hands and aprons that come in contact with carcasses.
- Implement decontamination and antimicrobial interventions using appropriate critical operational parameters.

Stunning

There are several ways to stun hogs that comply with FSIS regulations, including carbon dioxide (CO_2) (9 CFR 313.5), captive bolt (9 CFR 313.15), gunshot (9 CFR 313.16), and electrocution (9 CFR 313.30). These methods must immediately render the animal unconscious and insensible to pain. Appropriate stunning methods are required for an establishment to comply with the Humane Methods of Slaughter Act. Stunning can also affect the quality of meat, including its color, tenderness, and water-holding capacity (Rosenvold and Andersen, 2003). CO_2 stunning and the electro-narcosis stunning methods have no effect on carcass microbiology (Dehalle *et al.*, 2008). Captive bolt stunning is not expected to affect *Salmonella* prevalence, but there have been no research studies identified regarding its prevalence using this method.

Bleeding

The bleeding process results in a significant accumulation of body fluids, feces, and dirt on walls and floors and is a common source of cross-contamination. The percentage of carcasses contaminated with *Salmonella* is increased after bleeding (Bolton *et al.*, 2002b). FSIS recommends establishments take care to avoid carcasses touching the floor since the floor has been identified as a source of pathogens, including *Salmonella* (Mafu *et al.*, 1989; Hald, 1999).

FSIS recommends that knives are sanitized between each carcass; a study showed that stick knives tested positive for *Salmonella* and may be a source of cross-contamination (Botteldoorn *et al.*, 2003). Further, the efficiency and control of knife use is important to prevent wounds that are too deep. Deep wounds may penetrate the oropharynx or may introduce scald water and pathogens, such as *Salmonella,* into the pleural cavity.

Scalding

FSIS recommends establishments consider the type of hog, season, and the equipment used to determine and support the appropriate scalding temperature and duration. The cleanliness of the hogs and the status of the scald water were factors significantly associated with *Salmonella* on the carcasses at the end of the slaughter process in one study (Letellier *et al.*, 2009). Another study showed that inadequate scald tank temperatures can increase bacterial contamination (Gracey, 2015). Drag-through scalding tank water maintained at a minumum of 60ºC/140ºF has been shown to reduce bacterial load by as much as 4-log. Scalding at 61°C/142°F or higher for at least 8 minutes may be adequate if the duration is adequate (Bolton *et al.*, 2002b; Hald, 1999). Control of time and temperature as well as monitoring these values have been shown to reliably reduce the risks of carcass contamination and the spread of *Salmonella* in finished pork products (Bolton *et al.*, 2003). In very small establishments where scalding and dehairing processes are often performed during the same step, FSIS recommends the temperature of the water be above 62°C/144°F to ensure that *Salmonella* and other bacteria, both in the water and on the carcass, are destroyed during scalding (Hald, 1999; Davies *et al.,* 1999; Mafu *et al.,* 1989).

Vertical scalding using steam, where the vertical scald tunnel is maintained at a minimum temperature of 61ºC/141.8ºF for 6–7 minutes, eliminates contamination concerns related to the carcass contact with contaminated water in a scald tub. The vertical scalding technique gives the benefits of scalding, but removes the possibility of scald water contaminating the meat through the stick wound. Vertical scalding also decreases bacterial contamination of lungs and reduces the chances of muscular degeneration and the development of pale, soft, exudative muscle. Additionally, the internal temperature of the meat does not exceed 41°C/105°F (Gracey, 2015). Vertical steam scalding reduces both water consumption and operating costs as the cooling water from the condenser in the steam tunnel can also be used in the dehairing machine.

FSIS recommends establishments take the steps below to ensure that scald water is at the correct temperature and to minimize contamination:

- Evacuate feces from the rectum or implement an anus bunging system (coning);
- Wash the evacuated carcass before scalding;
- Ensure that the scalder is easy to clean, in good condition, and repaired promptly to maintain sanitary conditions;
- Maintain a clean supply of water. Change the scald water at least daily to prevent organic load build up;
- Drain and clean the scalder at least daily, paying particular attention to weld sites and rough, scratched areas in the interior of the tank to ensure effective cleaning;
- Remove or prevent accumulations of hair and organic matter from the scalder and dehairing machine both before and during operations;
- Control condensation within the facility as needed to maintain sanitary conditions;
- Ensure that water recirculation does not result in hair and residue accumulation and does not affect temperature control;
- Use a counter current application, which is fresh or recirculated scald water that flows into the scalder in an opposite direction from that of the carcasses, to increase heating efficiency and water cleanliness;
- Add an anti-foaming agent to the scald water to reduce organic load build up in foam if a water system is used; and
- Use vertical steam scald at 100°C/212°F for a constant supply of clean steam to prevent an organic load to accumulate.

Dehairing

Carcasses commonly pass through a scald tank to loosen hair before the dehairing machine removes hair. Dehairing machines often use high-speed, metal-tipped rubber flails to strip hair from the carcass. This process, while removing hair, also disturbs dirt, pathogens, and other contaminants from the carcass skin. It can cause feces to leak from the anus, and purge stomach contents. As a result, the equipment becomes contaminated and can lead to cross-contamination of carcasses. Dehairing equipment is a major source of bacterial contamination (Davies *et al.*, 1999; Gill and Bryant, 1993; Gill and Jones, 1995; Morgan *et al.*, 1987; Yu *et al.*, 1999; Food Refrigeration and Process Engineering Research Centre, 2007) with 4.4 to 6.2-log bacteria in the dehairing equipment 3 hours after slaughter begins (Rivas *et al.*, 2000). Contamination in the dehairing machinery is typically due to fecal material voided from the bung during dehairing. To prevent fecal contamination of dehairing equipment and to prevent cross-contamination, establishments should use a plastic cone, inserted into the anus (Morgan *et al.*, 1987). Anal plugging is effective to prevent fecal leakage during processing and is recommended in combination with anus-washing prior to scalding and dehairing to further reduce contamination (Purnell *et al.*, 2010).

FSIS recommends establishments take measures to ensure that dehairing is effective and efficient. Some best practices, depending on the equipment type used, are to:

- Clean and disinfect dehairing equipment regularly;
- Remove all organic material and debris from dehairing equipment at the end of the production day by washing thoroughly with water or disinfectant (Bolton *et al.*, 2002);
- Use hot water that is temperature-controlled between 60°C–62°C/140°F–144°F in the dehairing machine, if the water is not chemically treated (7 ICMSF, 1998);
- Use methods to prevent fecal voiding before dehairing (Bolton *et al.*, 2002b);
- Have procedures in place to clean contaminated carcasses that void fecal material after dehairing and prior to gambrelling and rehanging;
- Prevent cutting through the skin to reduce introducing bacteria into the interior of the carcass; and
- Use an extremely sharp knife for hand shaving.

While these steps are important, research indicates that cleaning and disinfection can be ineffective if the disinfectant does not reach all areas of the equipment due to poor design (Rivas *et al.*, 2000). FSIS recommends establishments ensure that equipment can be cleaned and disinfected to comply with 9 CFR 416.3. Some establishments may find using a clean-in-place (CIP) system throughout production beneficial since it can be applied on an ongoing basis; however, such a system requires significant investment and appropriate equipment. FSIS recommends establishments use a multi-hurdle intervention approach (Multi-Hurdle Intervention Approach) because while washing carcasses with hot water and applying antimicrobial interventions can reduce pathogen numbers, the potential for reintroduction of contamination in later processing steps can inhibit the effectivesness of washing alone (Bolton *et al.*, 2002a).

Salmonella has also been detected in air samples at the locations of dehairing and evisceration operations (Pearce *et al.*, 2006). Further, *Salmonella* can survive in aerosols at 24°C/75.2°F and 75% humidity for periods exceeding 24 hours (McDermid and Lever, 1996). One Irish study found the calculated contribution of airborne *Salmonella* to carcass contamination in the slaughter establishment to be negligible, although the airborne *Salmonella* levels in the studied establishments were sporadic (Okraszewska-Lasica *et al.*, 2014). FSIS recommends establishments minimize airborne contamination by ensuring adequate ventilation and control air flow in the establishment to separate the highly contaminated areas (*e.g.*, kill line) from areas with low levels of contamination (*e.g.*, cooler) (Bolton *et al.*, 2002b).

KEY DEFINITIONS

Critical operational parameters are the specific conditions that an intervention must operate under for it to be effective.

These may include conditions such as chemical concentration, length of time for application, pH, temperature, pressure, contact time, product coverage, spatial configuration, and equipment settings or calibration.

Singeing

Singeing, or burning of hair, is a key step to reduce microbiological contamination, including *Salmonella*, on hog carcasses (Saide-Albornoz *et al.*, 1995; Bolton *et al.*, 2002; Pearce *et al.*, 2004; Alban and Stark, 2005; James *et al.*, 2007). Singeing can remove *Salmonella* on the surface of the carcass very effectively. Various studies have shown that singeing achieves a 2.5–3.0 log_{10} CFU/cm^2 reduction in total microbiological load (Bolton *et al.*, 2002; Pearce *et al.*, 2004) and a reduction of *Salmonella* incidence from 7% to 0% (Pearce *et al.*, 2004). A single singeing process can decrease APC presence 2.2–2.5 log_{10} CFU/cm^2 (Dehalle *et al.*, 2008), although some bacteria may continue to survive in hair follicles and skin folds at the base and within the ears. Establishments should be aware that these areas can serve as a source of recontamination in later processing steps, such as polishing. FSIS recommends that knives be sanitized frequently at establishments that do not singe, but instead use skinning to remove the hair and hide.

Steam and Hot Water Vacuuming

Pork-producing establishments use hot water, steam pasteurization, and organic acid washes to control *Salmonella* and prevent outgrowth at various points throughout the process. The efficacy of these interventions can vary depending on the specific critical operational parameters used, including water temperature, water pressure, length of application, and chemical concentration. *Salmonella* prevalence changes are associated with washes, sprays, and steam decontamination treatments on pork carcasses; however, there is no strong evidence for the efficacy of one particular intervention over another (Totton *et al.*, 2016). The initial level of carcass contamination and bacterial attachment to the meat surface can also influence the effectiveness of interventions. Automated spray cabinets or handheld sprayers may be used, bearing in mind that effectiveness of the interventions vary based on the critical operational parameters used, and appropriate scientific support is required for establishments using interventions. As is stated above, FSIS recommends establishments use a multi-hurdle approach (Multi-Hurdle Intervention Approach) to reduce carcass contamination throughout the process, so interventions are not overwhelmed by the incoming bacterial load.

Prechill hot water washes and steam pasteurization are effective for reducing *Salmonella* contamination on pork carcasses. Hot water decontamination, where each carcass is sprayed with 80°C/176°F hot water for 12–15 seconds, reduced *E. coli* and *Salmonella* spp. by more than 2-log (Alban and Sorenson, 2010).

The surface of a hog carcass has many pores. Sanitizing solutions may not enter the pores in the skin because surface tension prevents the liquid from entering the pores. Vacuuming, however, works to remove the air and moisture from the carcass pores, and when the steam is applied, the bacteria can be readily killed. This process of vacuuming and steaming has been shown to reduce pathogen load by 1.0–2.0 log (Kozempel *et al.*, 2003). In addition, one study showed combining hot steam and spraying with a lactic acid solution reduced the surface microbiological counts and slows microbiological growth during storage (Pipek *et al.*, 2006).

Steam and hot water vacuuming are important decontamination procedures that can be applied at different points throughout slaughter and processing. Such treatment can be used to prolong the shelf-life and to increase the safety of pork carcasses (Pipek *et al.*, 2006). For small and very small establishments, household steam cleaners have been shown to be effective to reduce *Salmonella* and bacterial populations on hog carcasses (Trivedi *et al.*, 2007) while also remaining cost-effective and simple to operate.

FSIS recommends establishments take the following steps to ensure that steam and hot water vacuuming is effective and efficient:

- Use proper nozzle type and maintain appropriate temperature and pressure (Pipek *et al.*, 2006);

- Vacuum carcasses from the top of the hung carcass (back legs) to bottom (head) using 35°C/90–95°F steam (Pipek *et al.*, 2006); and

- Clean the equipment frequently on a regular schedule.

Polishing

> **KEY POINTS**
>
> Polishing is a primary mode of pork carcass recontamination after singeing.
>
> Polishers must be cleaned thoroughly and daily.
>
> Avoid using excess water during polishing to reduce the spread of microbiological contamination across the carcass.

Scalding and singeing can greatly reduce bacteria on the skin of the hog; however, the skin is often re-contaminated when the carcass passes through dehairing and polishing equipment (Yu *et al.*, 1999). The polishing machine is a tool used to remove loose hair and soot from the carcass, leading to visually cleaner carcasses. Polishing is a primary mode of pork carcass recontamination following microbiological reductions that were achieved during singeing (James *et al.*, 2007; Bolton *et al.*, 2002b; Snijders *et al.*, 1984; Gill *et al.*, 1995; Hald, 1999; Hald *et al.*, 2003). While polishing creates the appearance of a cleaner carcass it is a frequent contamination point, because bacteria that remain in skin folds, ears, and hair follicles after singeing can be redistributed across the carcass by polishing (Channon, 2014). Surviving bacteria can be mechanically disseminated by stainless steel scrapers or nylon brushes used in polishing (Delhalle *et al.*, 2008). The polishing machine whips are difficult to clean and persistent bacteria can form biofilms. Buildup of bacteria on the polishing machine throughout the slaughter day leads to subsequent bacterial transfer onto the carcass surface (Yu *et al.*, 1999). Therefore, FSIS recommends polishers be cleaned thoroughly to prevent harborage and multiplication of bacteria to high levels (Borch *et al.*, 1996; Huis in't Veld, 1992). To reduce carcass contamination and comply with 9 CFR 416.3, FSIS recommends that establishments clean and disinfect polishing equipment to reduce the level of carcass contamination and the prevalence of *Salmonella* in finished pork products (Hald *et al.*, 2003).

Polishing carcasses contaminated with feces may make this microbiological contamination invisible, allowing it to go undetected during subsequent visual inspections. Excessive water used in polishing has been shown to increase the spread of potential microbiological contamination over the carcass; therefore, FSIS recommends an additional singeing step after polishing to reduce total bacterial counts (Spescha *et al.*, 2006; Dehalle *et al.*, 2008; Zwirzitz *et al.*, 2019).

Knife Trimming and Shaving

Before treating carcasses with a pre-evisceration rinse or spray, establishments should remove visible fecal contamination in accordance with 9 CFR 310.18(a). If steam or hot water vacuuming is not available, knife trimming can be used to remove fecal contamination and other visible contamination. Knife trimming reduces the volume of microbiological contamination that might otherwise be diluted and spread by washing after singeing.

Microbiological contamination of knives and boots, the number of gut ruptures, mechanical problems or other factors that increased the potential for carcasses contacting one another, which are common process points for handling and cross-contamination, were factors significantly associated with the prevalence of *Salmonella* on the carcasses in studies (Botteldoorn *et al.*, 2003; Letellier *et al.*, 2009). In fact, the study by Letellier *et al.* showed that reduced frequency of knife washing between abdominal cavity cuts increases carcass contamination. Establishments can increase the time of immersion and temperature of water to result in significant bacterial reduction on knives. The available literature provides several options for an establishment to consider based on its process. Knife dips at temperatures of 70°C/158°F, 75°C/167°F, and 80°C/176°F for longer than 10 seconds resulted in equal, or greater, bacterial reduction than a brief dip in 82°C/180°F water (Goulter *et al.*, 2008). FSIS recommends establishments ensure that employees are dipping knives for a sufficient length of time or provide multiple knives for employees to rotate between as they continue to make cuts to minimize microbiological cross-contamination. FSIS recommends knife rotation, which allows the knives to remain in the sanitizing solution for at least 30 seconds (Tapp *et al.*, 2013). FSIS also recommends establishments monitor the temperature of the water baths to maintain maximum levels of bacterial reduction. Ambient-temperature sanitizing treatments of 200 ppm quaternary ammonium, 200 ppm chlorine, and 5% lactic acid show the greatest reductions of *Salmonella* (Tapp *et al.*, 2013). Organic debris from the knives will decrease the effectiveness of any sanitizer; therefore, FSIS recommends establishments ensure that organic debris is removed as necessary. FSIS also recommends sanitizing solutions be changed out per manufacturer recommendations to achieve the maximum level of bacterial reduction.

Knife scabbards and sharpening steels can easily become sources of microbiological contamination during the slaughter process. Therefore, FSIS recommends scabbards be used only for safe transportation of knives to and from the employee's workstation. Knives should then be stored in the sanitizing solution in between uses. In addition, FSIS recommends knives be sterilized after making contact with the sharpening steel to prevent cross-contamination. FSIS recommends sharpening steels be sterilized as needed and stored in a sanitary manner in between uses, such as hanging from an easily accessible hook at the workstation. They should not be stored in lavatory sinks or dangle from an employee's belt where they may make contact with boots or other insanitary surfaces (Gracey, 2015).

Pre-Evisceration Carcass Rinse or Spray

A listing of suitable compounds that can be used for pre-evisceration rinsing or spraying is detailed in FSIS Directive 7120.1. Organic acid washes are effective for reducing the prevalence of *Salmonella* on pork carcasses. Carcass spray washes with organic acids decrease *Salmonella* load (Epling *et al.*, 1993). Applying organic acids after carcass washing reduces bacterial load; however, one study found the reduction is not statistically different from hot water washing alone (Eggenberger-Solorzano *et al.*, 2002). Both hot water and acidified sodium chlorite treatment of carcasses reduced *Salmonella* and *E. coli* (Hamilton *et al.*, 2010).

Best practices when using pre-evisceration carcass rinses and sprays include:

- Trim open abscesses, septic bruises, parasites, and parasitic lesions before the carcass enters the cabinet;
- Monitor pressure, if pressure is used to spray carcasses, to prevent driving microbiological contamination into the tissue;
- Monitor concentrations and temperatures regularly to verify effectiveness;
- Consider using stainless steel cabinets with multiple spray nozzles to ensure complete carcass coverage;
- Ensure complete carcass coverage when applying antimicrobials with a hand spray applicator;
- Verify that equipment is used in a manner that prevents cross-contamination of adjacent carcasses;
- Prevent carcasses from touching; and
- Consider using a post-evisceration rinse or spray to further reduce carcass contamination.

Head Washing and Head Dropping

FSIS recommends a head wash system to reduce *Salmonella*. One study found washing pork cheeks and heads with 40ºC/104ºF water significantly reduced *Salmonella* prevalence from 7.15–5.77 $\log_{10}$CFU/cm^2. The same study showed that a 2% acetic acid treatment to cheek meat reduces *Salmonella*, APC, and coliform load by 67% (Frederick *et al.*, 1994). Splitting the head increases contamination on the sternum, and research shows that *Salmonella* presence has the highest prevalence on the foreleg, head, sternum, and throat (Biasino *et al.*, 2018).

Best practices for head washing and head dropping include:

- Flush the oral cavity with room-temperature water removing ingesta or other contaminants before head dropping and FSIS head inspection;

- Maintain and sanitize head dropping equipment, as necessary, between carcasses;
- Sanitize knives frequently and properly; and
- Maintain and sanitize knives and equipment whenever the oral-pharyngeal cavity is sectioned or there is exposure to stomach contents.

Bung Isolation

FSIS recommends establishments bag and tie the bung before evisceration, ensuring staff pay specific attention to minimizing cross-contamination of the carcass and viscera.

Best practices for bung isolation include:

- Tie bung, cut free from surrounding tissues with a single incision, and cover area with a protective covering;
- Prevent contact of bung with carcass or with viscera during separation;
- Secure bag with a tie or clip;
- Ensure employee hygiene and use of personal protective equipment, such as gloves and aprons;
- Immediately remove any visible contamination that results from bunging;
- If possible, use an automated bunging system called “bung guns” instead of manual bung tying. An automated bunging system will reduce cross-contamination, by going around the anus and evacuating the rectum; and
- Properly maintain and sanitize bung guns, knives, and hooks, as necessary, between each carcass.

Evisceration

Pork carcass evisceration and carcass splitting are associated with *Salmonella* prevalence increases. Evisceration is an important point in the establishment’s process where effective interventions can have a positive effect in controlling *Salmonella* (O’Connor *et al.*, 2012), especially as the foreleg and head are highly contaminated after evisceration due to carcass positioning (Biasino *et al.*, 2018).

Best practices for evisceration include:

- Remove all hair, scurf, and dirt from the hooves and carcass and thoroughly wash the carcass before evisceration;
- Ensure skilled and experienced individuals perform evisceration;
- Avoid cutting or rupturing the gut;
- Remove the pluck with the gullet and viscera attached, so there is no leakage;
- Remove carcasses with visual contamination for reconditioning (by knife trimming or steam vacuuming) before carcass splitting; and
- Avoid cross-contamination, which occurs when carcass splitting saw blades come in contact with the spinal column or throat (Dehalle *et al.*, 2008) and disinfect carcass splitting equipment after each use.

Lymph Node Removal

One scientific model estimated an average of 45 cases of salmonellosis per 100,000 American citizens annually due to the consumption of wholesale ground pork (Zhang, *et. al*., 2019). Recent theories suggest that lymph nodes may harbor *Salmonella*. This is a developing area of research on swine, and currently, data is sparse. Research in this area is ongoing.

Slaughter and dressing processes as well as typical interventions used to reduce pathogens on carcass surfaces are not effective at reducing pathogens that are protected within the lymph nodes. Comprehensive systematic control of *Salmonella* should include addressing the potential presence of *Salmonella* from the inclusion of lymph nodes in product intended to be used in ground pork or other non-intact cuts.

Pre-Chill Final Rinse, Hot Rinse, and Steam Pasteurization

Processing procedures, such as decontamination treatments after evisceration and carcass splitting, generally result in decreased prevalence of *Salmonella* as the carcasses move toward the cooler (O'Connor *et al.*, 2012). FSIS recommends carcass decontamination treatments before chilling, including organic acid washes, hot water washes, and steam pasteurization, that achieve a carcass surface temperature of at least 70°C/158°F during treatment (Food and Agriculture Organization of the United Nations, World Health Organization, 2016).

Establishments may improve decontamination by adding antimicrobial chemicals, such as chlorine or trisodium phosphate (Bolton *et al.,* 2002). In several studies, a pressurized, dilute 2–3% lactic acid or acetic acid has been shown to reduce pathogen presence (Van Netten *et al.*, 1995; McMullen, 2000). Additionally, a 2% lactic acid solution at 55°C/131°F applied for more than 60 seconds, 13–23 psi at final carcass washing is an effective decontamination measure (Van Netten *et al.*, 1995).

Best practices include:

- Monitor drains to ensure they are working properly and prevent backup that may result in carcass and equipment contamination;
- Divert carcasses for cleaning to a holding rail when carcasses are contaminated and not adequately cleaned before the final wash;
- Clean contaminated carcasses, by trimming or using steam or hot water vacuuming, to remove visible contamination prior to final inspection and final washing;
- Rinse hanging carcasses from the top (back legs) down;
- Minimize splash onto other carcasses;
- Deliver water or steam to the entire surface of the carcass at a temperature of at least 70°C/158°F when using a thermal pasteurization system;
- Control pressure to prevent excess pressure from driving microbiological contamination into the tissue;
- Improve decontamination by applying antimicrobials or hot water; however, due to cost, some very small operations may choose to use cold water to wash carcasses; and
- Consider careful treatment of necks and inside jowls when the head is separated from the carcass.

Spray Chilling

Chilling is the point in the process where the carcass temperature is reduced. Temperature control and sanitation measures ensure the microbiological load reductions affected by the interventions are maintained. Temperature control limits pathogen outgrowth and sanitary measures prevent recontamination.

Establishments use spray chilling, an evaporative cooling method through the application of chilled water to the carcass, early in post-mortem cooling, but after all other slaughter dressing and interventions, to control carcass shrinkage and quickly chill carcasses. Intermittent spraying of cold water onto carcasses during the first 3–8 hours after slaughter allows the carcass surface to remain wet and allows for evaporative cooling without increasing carcass weight loss. Pork carcasses have high muscle temperatures and low pH, which can affect the development of pale, soft, and exudative pork. FSIS recommends establishments ensure a rapid chilling process to a recommended internal muscle temperature of 10ºC/50ºF at 12 hours and 2ºC/36ºF–4.4ºC/40ºF at 24 hours (Savell *et al.*, 2005). Blast-chilling and spray-chilling have been shown to reduce carcass shrinkage. For establishments that hold carcasses more than one day, FSIS recommends establishments spray chill carcasses using an organic acid spray two days prior to fabrication to maximize reduction of *Salmonella* (Algino *et al.*, 2009) and maintain the cooler at a temperature that ensures carcasses will have an internal temperature of 4.4°C/40°F within 24 hours.

FSIS recommends establishments use best practices to chill carcasses, including:

- Begin carcass chilling within approximately one hour after bleeding to limit pathogen outgrowth;

- Begin chilling offal products and variety meats as quickly as possible after removal from the carcass to limit pathogen outgrowth;

- Maintain coolers at a temperature that ensures carcasses will have an internal temperature of 4.4°C/40°F or less within 24 hours after entering the cooler and that this temperature is maintained for all products;

- Maintain finished product storage areas at 4.4°C/40°F or lower or have supporting documentation and validation for other temperature limits chosen;

- Provide adequate distance between carcasses, walls, and equipment to prevent cross-contamination and allow for efficient air circulation to prevent condensation;

- Ventilate coolers with negative-pressure systems to prevent cross-contamination from airflow from slaughter operations;

- If carcasses are held longer than 7 days in the cooler before fabrication, maintain scientific support for cooler operating parameters to include temperature, humidity, and air flow;

- Transport carcasses for hot-boning (deboned before chilling) to the boning areas directly from the slaughter department. Do not delay boning. Maintain the boning room environmental temperature at 10°C/50°F or lower;

- Ensure that employees maintain proper hygiene practices to prevent the creation of insanitary conditions; and

- Establish traffic patterns to eliminate movement of personnel, pallets, and refuse containers between slaughter and further processing. If employees must work in both areas, have procedures in place that require the employees to change outer and other soiled clothing, wash and sanitize hands, and clean and sanitize footwear before moving from slaughter to further processing areas.

Finished Pork Product Fabrication, Interventions, and Processing

As previously discussed, microbiological contamination can be minimized with the use of proper sanitary dressing procedures and through the application of antimicrobial interventions during slaughter. Further, FSIS recommends establishments include measures to control *Salmonella* cross-contamination and outgrowth in fabrication and further processing of pork carcasses into intact and non-intact pork cuts and comminuted pork.

FSIS has provided guidance for establishments when designing HACCP plans as shown in the HACCP Model for Fresh Ground Pork Sausage Patties.

FSIS defines an **intact pork cut** as a cut derived from a pork primal cut that has not been subjected to processing that renders it non-intact. A **non-intact pork cut** is also a cut derived from a primal cut but has been injected, mechanically tenderized, reconstructed, vacuum-tumbled, scored and marinated, or otherwise processed to render it non-intact. FSIS defines **comminuted pork** as pork that has been ground, mechanically separated, or otherwise processed to reduce particle size. Based on FSIS sampling data, the prevalence of *Salmonella* in comminuted pork is about 30% and the combined percent positive for intact or non-intact pork cuts is about 9%.

One recent study found the prevalence of *Salmonella* on pork cheek meat and head trim without visible lymph node tissue to be between 63-68% (Wottlin *et al.*, 2022). This may be due to sanitary dressing defects during slaughter, as the esophagus and trachea are often incised during head dropping. As pork head meat and cheek meat are often incorporated into ground pork, FSIS recommends that establishments consider the prevalence levels of *Salmonella* in the incoming product used to make comminuted pork when designing their hazard analyses.

Recommended best practices for carcass fabrication include using antimicrobial interventions and maintaining and tracking the temperature of fabrication and boning rooms to at 10°C/50°F or less. Establishments are required to maintain sanitary conditions in the fabrication area, including all equipment, knives, and employee garments per 9 CFR part 416.

Temperature control is an important control mechanism to prevent pathogen outgrowth during product storage and at retail. When temperature abuse occurs, the risk of foodborne disease from the consumption of pork products increases. For raw pork products, cleaning cutting boards, controlling and monitoring refrigeration temperature, and reducing storage time are significant measures to control *Salmonella* (Swart *et al.*, 2016).

Using organic acids on pork products during final fabrication, while often effective in improving the microbiological quality of the meat, may cause quality concerns since the organic acids may cause irreversible changes in the color of retail cuts. Interventions used in the slaughter process, such as hot steaming and spraying with a lactic acid solution (Steam and Hot Water Vacuuming), have been shown to prolong the shelf-life and to increase the safety of pork carcasses and meat (Pipek *et al.*, 2006). Interventions used by pork slaughter processing plants greatly reduce the prevalence of *Salmonella* on carcasses from 91.2% at pre-scald to 3.7% at chilling. Because a low percentage of *Salmonella* is still found on finished, chilled carcasses, it is important for establishments to use additional interventions in pork processing plants to continue to reduce the risk of salmonellosis to consumers (Schmidt *et al.*, 2012).

As previously mentioned in the Vaccine and Bacteriophages Interventions section and included in FSIS Directive 7120.1, approved bacteriophages can be used to decontaminate food preparation surfaces and significantly reduce the population of susceptible *Salmonella* strains by approximately 2–4 logs on glass and stainless steel surfaces (Woolston *et al.*, 2013).

The most effective *Salmonella* mitigation strategies for ground pork, sausage, patties, or other comminuted pork product production are those taken at the end of the slaughter line and during post-processing (Bollaerts *et al.*, 2010). Recommended best practices may include heating, freezing, and multi-hurdle steps such as drying, curing, salting, and fermenting, irradiation, and high pressure processing (HPP). An SJ2 phage significantly reduced *Salmonella* presence in ground pork; however, larger reductions were seen at higher temperatures (21°C/69.8˚F) versus lower temperatures (4°C/39˚F) at 24 hours (Hong *et al.*, 2016). An establishment that chooses to administer interventions directly to ground product would need to comply with all labeling requirements and approved conditions of use per FSIS Directive 7120.1.

Packaging, Finished Product Storage, Transport, and Retail Products

In one study, *Salmonella* and other bacterial indicator data were evaluated at various temperatures to assist pork fabrication and grinding processors with data to validate critical limits. *Salmonella* Typhimurium and *Salmonella* Enteritidis growth was monitored in ground pork and boneless pork chops held at various temperatures to mimic typical processing and holding temperatures commonly observed in pork processing environments. No significant growth of *Salmonella* was observed in boneless pork chops held at refrigeration temperatures of 4.4–10ºC/39.9–50ºF, but significant growth was observed when held at room temperature (22.2–23.8ºC/72–74.8ºF). In ground pork, there was significant outgrowth of *Salmonella* at all times and temperatures studied except for the ground pork stored at 4.4ºC/40ºF. This study shows that meat processors can use a variety of time and refrigeration temperature combinations as critical limits to minimize *Salmonella* growth during production and storage of raw pork products (Mann *et al.*, 2004).

Salmonella contamination is found in both whole muscle and fresh ground product, but ground products may pose a greater risk to consumers, if the product is undercooked, because contamination is spread throughout the product during grinding. Retail raw meats are often contaminated with bacterial pathogens and are potential vehicles to transmit foodborne illness (Zhao *et al.*, 2001). The additional manipulation at retail stores, which can include portioning, re-packaging, and re-grinding, can be a source of *Salmonella* contamination (Duffy *et al.*, 2001). Retail shops that further process, cut, and grind meat have been found to have a higher prevalence of *Salmonella* on product compared to supermarkets (Hansen *et al.*, 2010) likely due to differences in retail store hygiene procedures, cross-contamination events, and mishandling of products. Chorizo, a ground sausage product, that is sold raw can contribute to salmonellosis illnesses since consumers frequently undercook the sausage due to its dark color (Escartin *et al.*, 1999; Hajmeer *et al.*, 2006).

Pathogen modeling has been used to predict the survival and growth of foodborne pathogens, such as *Salmonella*, in multiple product types. One group of researchers developed a model that can be used to design critical limits during processing of raw pork products where temperatures may be elevated for short periods of time (Kaur *et al.*, 2008). The University of Wisconsin also developed critical limits based on their research on pathogen growth at different temperatures. Those modeling results are available online at [CL Temp Abuse.pdf (wisc.edu)] and may be readily used by establishments.

FSIS recommends establishments ensure that the internal pork product, storage room, and transportation vehicle temperatures are maintained at 4.4°C/40°F or less by monitoring and documenting the temperatures.

Shipping Practices

Typically, establishments, or their contracted transportation companies, ship carcasses and final packaged products under refrigerated temperatures that they monitor and document as part of the food safety system.

9 CFR 310.18(c) includes provisions for establishments that hot-bone carcasses to test the carcasses following the final wash, so if an establishment hot-ships carcasses, the establishment must test the hot-shipped carcasses in a similar manner.

Under the regulations, there are no specific temperature requirements to ship hot carcasses (hot-ship). However, the establishment must address all potential hazards in the hazard analysis (9 CFR 417.2(a)(1)). Per this regulation, the establishment must be able to support decisions in the hazard analysis to hot-ship carcasses without a chilling procedure. Dwell times between 10°C–54°C/50°F–130°F, particularly when held over 6 hours, can be hazardous because of pathogen outgrowth. The establishment must be able to identify why hazards are not reasonably likely to occur (NRLTO) when diverting a product into commerce without a chilling procedure. Regulations require these potential hazards be addressed in the establishment's hazard analysis. If the establishment determines any potential hazards are NRLTO, the establishment is required to provide documentation supporting that determination.

FSIS also recommends establishments provide instructions with the hot-shipped product that, when followed, ensures the product is handled safely after it has been shipped.

In addition, the establishment is required to protect product from adulteration during processing, handling, storage, loading, and unloading at and during transportation from official establishments (9 CFR 416.4(d)). The hot-shipped carcasses cannot create insanitary conditions or be exposed to insanitary conditions.

Statistical Process Control

A process control procedure is a defined procedure, or set of procedures, designed by an establishment to provide control of those operating conditions that are necessary for the production of safe, wholesome food. The procedures typically include some means of observing or measuring system performance, analyzing the results generated in order to define a set of control criteria, and taking action when necessary to ensure that the system continues to perform within the control criteria. The procedure is likely to include planned measures that the establishment will take in response to any loss of process control. In addition, the procedures can be used as support for decisions made in the hazard analysis. Process control procedures are likely to include decontamination of carcasses, adequate sanitary dressing practices, antimicrobial intervention treatments, and implementation of best practices described throughout this guideline. Establishments that fail to control these procedures and treatments create the potential for microbiological contamination of carcasses and products.

Statistical process control (SPC) is a scientific method that uses statistics to analyze data collected by an establishment to monitor and improve processes by reducing variation from the process. The goal of process control in a slaughter establishment is to minimize microbiological contamination of the carcasses, reduce microbiological pathogens that may be present and injurious to health, control the proliferation of any remaining microorganisms, and prevent recontamination.

SPC provides a powerful tool for establishments to monitor and interpret data collected for ongoing HACCP verification. SPC can provide establishments with an early warning that the process may not be functioning as designed. This early warning can allow establishments to make modifications to bring the process back into control prior to failing a performance standard or individual establishment-identified, pre-determined performance criteria. SPC can provide establishments with reasonable assurance that the HACCP system is functioning as designed, and that they are likely to meet applicable performance standards.

Several methods and approaches for SPC are available for establishments to follow. Establishments should consider available guidance and develop a statistically valid approach for interpreting sample results, such as the information available in Saini *et al.*, 2011 and De Vries and Reneau, 2010.

Establishments often use indicator testing to assess process control. FSIS has guidance available for industry regarding microbiological sampling of indicator organisms in the FSIS Guideline: Modernization of Swine Slaughter Inspection Developing Microbiological Sampling Programs in Swine Slaughter Establishments.

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