Process Mapping the Prevalence of *Salmonella* Contamination on Pork Carcass from Slaughter to Chilling: A Systematic Review Approach

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Abstract

A systematic review was conducted to identify and summarize primary research studies that describe the prevalence of *Salmonella* spp. in pork from slaughter to cooler in the member states of the European Union (EU), Australia, Canada, Hong Kong, Japan, Korea, Mexico, New Zealand, Taiwan, and United States (i.e., a process map). Relevant studies documented *Salmonella* spp. prevalence at more than one processing point using the same cohort of pigs or the same production line for the post-cooler component. Literature searches retrieved 6811 citations. Sixteen publications, describing 44 studies, evaluated the presence of *Salmonella* on pork carcasses. The carcass sampling points evaluated were as follows: stun, bleed, kill, scald, dehair, singe, polish, bung removal, evisceration, split, stamp, final wash, immediately after chill, and 18–48 h after chilling. Seventy-eight comparisons of *Salmonella* spp. prevalence between points along the processing line were reported. The median prevalence of *Salmonella* spp.-positive carcasses evaluated in the cooler was 0%. The median prevalence of *Salmonella* spp. after bleeding was 32%. Fifty-nine of the 78 point-to-point comparisons were associated with either no change or a decrease in *Salmonella* prevalence as the carcass moved closer to the cooler. Nineteen point-to-point changes showed an increase in *Salmonella* prevalence as the carcass moved toward the cooler; of these, six reported a greater than 10% increase in *Salmonella* prevalence. The majority of increases were associated with post-evisceration and splitting. These findings suggest that the processing procedures in place generally result in decreased prevalence of *Salmonella* spp. as the carcasses move toward the cooler.

Introduction

*Salmonella* is one of the most important foodborne pathogens causing gastroenteritis in the United States, and it has been estimated that 9–15% of *Salmonella* spp. infections and 7.5% of *Salmonella* Enteritis and Typhimurium infections in humans are caused by the consumption of contaminated pork or processed foods derived from pork (Hald *et al.*, 2004; Pires *et al.*, 2010). Because *Salmonella* contamination of pork can be related to pre-harvest infection and post-harvest cross-contamination, efforts to reduce *Salmonella* in pork have focused on both pre- and post-harvest arenas (Alban and Stark, 2005; Botteldoorn *et al.*, 2004). Prior studies have suggested that one of the most economic and efficient places for applications of interventions to reduce *Salmonella* spp. contamination of pork may be during carcass processing (Alban and Stark, 2005; Denagamage *et al.*, 2007; O’Connor *et al.*, 2008). However, despite publicly available information describing effective interventions at individual points in the processing system, the combined efficacy within the processing system is poorly characterized. Information that describes the cumulative impact of control efforts over the entire system rather than at individual points is useful to consumers and decision makers as it enables them to understand the effectiveness or ineffectiveness of interventions employed during carcass processing. Such information would also enable the identification of the points of introduction, amplification or reduction of *Salmonella* along the system. Therefore, the objective of this review was to comprehensively and transparently synthesize reports of *Salmonella* prevalence reported from multiple studies in abattoirs and to quantitatively describe changes in *Salmonella* prevalence that might otherwise not be observable in single site studies.

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Methods

Protocol, review questions, and eligibility criteria

The review protocol was managed by the principle investigator (Dr. O’Connor) and outlined in a proposal to the two funding agencies, the National Pork Board and the American Meat Institute Foundation. This protocol was not registered, as there are currently no groups organized to register food safety or veterinary science reviews. The review’s aim was to describe changes in Salmonella prevalence on the carcass from slaughter to cooler. The specific review questions were refined based on a series of discussions in early 2007. Included in the discussions were Dr. A. O’Connor, Dr. J. Dickson (Professor of Microbiology at Iowa State University [ISU]), Dr. J. McKean (University Professor and Extension Swine Veterinarian at ISU), and Dr. S. Larsen (National Pork Board). As a result of those discussions, it was decided that the population of interest was pork during the production process from slaughter to cooler in the member states of the European Union (EU), Australia, Canada, Hong Kong, Japan, Korea, Mexico, New Zealand, Taiwan, and United States. These countries were considered relevant as they were thought likely to have similar modern slaughter facilities. The outcome of interest was the change in Salmonella prevalence in pork during the production process. The processing points were based on a article by Alban and Stark (2005). We did not impose date restrictions as it was unclear how various slaughter and processing procedures would relate to the review without reading the articles. Consequently, it was decided to consider the relevance of identified articles published prior to 1970 on an individual basis. We intended to only use publications in English because funds for translation were not available. Because the entire pork production process was of interest, the review was split into two specific areas: (1) slaughter to cooler and (2) cooler to shipping. The final review questions for the two areas were as follows:

Question 1 (slaughter to cooler): “What changes in carcass levels of Salmonella prevalence and quantity occur from slaughter to cooler in swine abattoirs based in the member states of the EU, Australia, Canada, Hong Kong, Japan, Korea, Mexico, New Zealand, Taiwan, and United States.”

Question 2 (cooler to shipping): “What changes in Salmonella prevalence and quantity occur from chilled carcasses to final products shipped from swine abattoirs based in the member states of the EU, Australia, Canada, Hong Kong, Japan, Korea, Mexico, New Zealand, Taiwan, and United States.”

Literature search and information sources

Dr. O’Connor and a master’s level student in epidemiology (T.D.) who had conducted several prior systematic reviews on Salmonella in pork designed the search terms for each question separately. The slaughter-to-cooler search combined the population string “Hog or hogs or swine or pig or pigs or gilts or sows or market-weight or finishes or boars or porcine or piglet” with processing point terms as follows “lairage, lairage-time, pens, pre-slaughter, swine housing, animal housing, preslaughter handling, housing, holding pen, preslaughter holding, environment, holding, abattoir pen, abattoir pens, pre-harvest holding, preslaughter holding, preslaughter holding pen, preslaughter holding pens, stun, stunning, slaughter, bleed, bleeding, haemorrhage, scald, scalping, scraping, dehair, dehairing, flaming, singeing, singe, evisceration, carcass halving, carcass opening. Searches for the slaughter-to-cooler review were conducted from inception to October 2010 on the following databases: PubMed (1956 to Oct. 2010), Agricola (1970 to Oct. 2010), CAB Abstract (1990 to Oct. 2010), AGRIS (1975 to Oct. 2010), MEDLINE (1950 to Oct. 2010), BIOSIS (1926 to Oct. 2010), Food Science Technology Abstracts (FSTA) Retrospective (1969–1989), Biological abstract (1980–1989), and Biological & Agricultural Index and FSTA (1989–2007). The reference lists of the final relevant manuscripts were also hand searched for relevant citations. The tables of contents from the Proceedings of The International Symposium on Epidemiology and Control of Salmonella in Pork (1996–2010), International Pig Veterinary Society (1996–2010), American Association of Swine Veterinarians/ Practitioners (1996–2010), and the Annual Reciprocal Meat Conference (for cooler-to-shipping review, 1999–2006) were hand searched for relevant citations. The original searches were conducted in February 2007 (slaughter-to-cooler) and February 2008 (cooler-to-shipping). The cooler-to-shipping search yielded so few usable studies that review was discontinued after the literature search and relevance screening (see results below). However, in October 2010 as the review neared publication, the slaughter-to-cooler search was updated, but the time period was limited to 2006–2010. The rationale for the overlap was to check the new 2006 and 2007 publications that had been missed in the 2007 search due to a lag in database updates and to verify that the October 2010 search identified the same set of literature.

Study selection and relevance screening

The purpose of the review was to develop a process map of Salmonella in pork. Studies were considered relevant, and therefore eligible for the review, if they documented Salmonella prevalence at more than one processing point using the same cohort of pigs or same production line. We limited the review to multiple point studies, as this review focused on developing a process map for carcass production. It is known that Salmonella prevalence varies greatly between groups of hogs; therefore, single point studies provide estimates of point prevalence. Such information has been reviewed elsewhere (Fosse et al., 2009). Studies designed to assess interventions or conducted in artificial production settings were not considered relevant.

After identifying the citations, three levels of relevance screening were employed for the slaughter-to-cooler review. Two reviewers evaluated each citation independently. Two research staff and two graduate students in the principal investigator’s research group, conducted the first and second level of screenings based on the title and abstract. Conflicts were resolved by seeking the opinion of the principle investigator. For the third screening level, based on the full manuscript, the reviewers were either a master’s or doctoral level student in the epidemiology of food safety or the principle investigator. Conflicts were resolved by discussion between the two reviewers.

For the slaughter-to-cooler review, the screening questions at the first level were as follows:

- Does the abstract and/or title report primary research?
- Does the abstract mention the isolation of Salmonella from pork at slaughter?
Risk of bias in individual studies

As we were not comparing interventions, biases associated with interventions (such as allocation, masking, and loss to follow-up) were not assessed. Further, we did not exclude manuscripts based on potential quality measures for prevalence surveys such as random selection of carcasses from the study population for three reasons. First, our prior experience suggested that few, if any, of the publications would include such information and such a criterion would exclude all publications. Second, our experience is that random selection methods are very difficult to execute in abattoirs. Third, we could not anticipate that haphazard or convenient selection would introduce a unidirectional bias.

A second potential source of bias was the diagnostic test employed by each study. Obviously, the sensitivity and specificity of the culture methods varied between studies. The use of paired data within the plants was employed as an indirect method of adjusting for these differences between studies. For example, a method with low sensitivity would have the same low sensitivity at all processing points in the plant but would still correctly capture the trend, if not the magnitude, of *Salmonella* prevalence across the system (i.e., increasing, decreasing, or remaining stable).

Summary measures and synthesis of results

The distribution of the prevalence of *Salmonella* was reported for processing points that had at least three studies reporting data on that processing point. Descriptive data reported were the minimum, the 25th quartile, median, the 75th quartile, and maximum prevalence for each processing point. Scatter line plots and box-and-whisker plots were used to describe the data. For the box-and-whisker plots, the box represented 50% of observations (i.e., the bottom and top ends of the boxes are the 25th and 75th quartiles, respectively). The whiskers presented the full range of data. When the whiskers are missing, the range is the same as the 25th or 75th quartile. The box-and-whisker plots were overlaid with a jitter plot of all the data points used in calculation of the box and whisker plot.

Further descriptive analysis included determination of the direction and frequency of point-to-point changes in *Salmonella* prevalence along the processing line. Point-to-point changes referred to the change in prevalence from one point to the next in the study-sampling scheme. For example, a study that sampled at bleed, singe, and chill would have two point-to-point changes: the change in prevalence from bleed to singe, and the change in prevalence from singe to chill.

Results

Results of slaughter-to-cooler

A total of 6811 citations were identified by the searches for the slaughter-to-cooler review. The vast majority of articles and eventually relevant articles were found in PUBMED, CAB, and Agricola. After removing the vast majority of articles during the three screenings, we identified 16 manuscripts that described sampling of carcasses at more than one processing point in a swine abattoir. In these manuscripts, eight were identified in PUBMED, CAB, and AGRICOLA; one was unique to CAB; one was unique to AGRICOLA; one was found in the Proceedings of the 1st International Symposium
Table 1. Slaughter-to-Cooler Articles That Were Potentially Relevant But Could Not Be Located

- Bouvet, J., C. Bavaï, R. Rossel, A. Le-Roux, M.P. Montet, C. Mazuy, and C. Verneyoz-Rozand. 2003. Evolution of pig carcass and slaughterhouse environment contamination by *Salmonella*. Revue de Medecine Veterinaire 154:775–779. [This report was not available although it was requested through Interlibrary Loan.]

- Canteras, A.C., and J.C. Bernardo. 1996. Incidence of *Salmonella* contaminations among slaughtered pigs in selected abattoirs of Metro Manila [Philippines]. Araneta Research Journal 34:71–74. [This report was said to be located in the Araneta Research Journal; however, the response from the library indicated that the journal was not published at the time this research article was said to be published.]

- Chung, G.T. 1977. Comparison of various sites of slaughtered pigs for the isolation of *Salmonella* organisms. Journal of Veterinary Science Seoul University 2:38–42. [An attempt was made to locate this report in the Journal of Veterinary Science Seoul University, 1977, volume 2, issue 2, pages 38–42; however, the Journal of Veterinary Science is only recorded to exist from the year 2000 to the present. When the publisher's website was located, it was discovered to be only in Korean.]

- Donahue, J.M., and S.J. Locke. 1985. Salmonellosis in swine in Kentucky. Progress report, Kentucky Agricultural Experiment Station, 51–52. [This report was not available, although it was requested through Interlibrary Loan.]

- Fuchs, J. 1983. Prevalence of *Salmonella*ae of healthy slaughter pigs in Austria. [Locating this report was not possible because the electronic citation has insufficient information; upon attempting to locate through general internet searches of title and author, more information could not be located.]

- Holst, S. 1993. *Salmonella* infection in Danish slaughter pigs. Dansk Veterinaertidsskrift 76:645–652. [Although this journal was located, the article could not be found.]

- Huisman, W. 1950. The occurrence of *Salmonella* in healthy pigs. Utrecht. [This article could not be located because the electronic citation has insufficient information. Through a general internet search, this was identified as a thesis published in Utrecht, but we could not find the publication or any further information. We requested the article through Interlibrary Loan but received no response.]

- Korsak, N., B. Groven, B. Jacob, G. Daube, and E. Flamant. 2002. Prevalence of *Salmonella* along a meat pork production system. Wageningen, The Netherlands: Wageningen Academic Publishers. [Wageningen Academic Publishers was contacted on September 18, 2007, but we received no reply. When we ordered the proceedings for Food Safety Assurance in the Pre-Harvest Phase, the abstract was missing.]

- Morgan, I.R., F.L. Krautil, and J.A. Craven. Reduction of *Salmonella* contamination on pig carcasses. [Insufficient information was provided in the electronic citation database. We attempted to locate the article using a general internet search of the authors and title, but no results returned.]

- Pless, P., and Koefer, J. Prevalence of *Salmonella* in Styrian slaughter pigs. Proceedings with the Program. Zbornik’s programom. Ljubljana (Slovenia, 1998, pp. 136–137). Slovene Microbiological Societe, Ljubljana. Bole-Hribovsek, V., Ocepek, M., and Klun, N. Slovene Microbiological Society. [This article could not be located. Using a general Internet search, it was found that this reference should be on pages 126 and 137 of the Proceedings from the Slovene Microbiological Society. However, Interlibrary Loan could not locate these proceedings.]

- Riza, B.F., O.L. Ariza V, M.F. Bustos, and B.-N.E. Pena. 1983. Prevalence of *Salmonella* sp. in pigs at two summary slaughterhouses in Bogota Columbia. Revista del Instituto Colombiano Agropecuario 18:501–506. [Volume 18 of this journal was a special issue and was not available according to the Interlibrary Loan.]

- Schutz, G. 1958. Occurrence of rare *Salmonella* types in bile and faeces of healthy slaughtered cattle and pigs. [This article was not located because of insufficient information in the electronic citation. We attempted to gather more information by searching internet search databases and doing a general internet search for title and author, but we found no further information.]

- Sisak, F.M.S., H. Havlickova, R. Karpiškova, and I. Rychlik. Prevalence of *Salmonellaeae* and their resistance to antibiotics in slaughtered pigs in the Czech Republic. n.d. [This article could not be located because of insufficient information in the electronic citation. It was found to be located in the Czech Journal of Food Sciences; however, this journal could not be located by Interlibrary Loan.]

- Stern, H. 1938. The incidence of *Salmonella* in abattoir pigs at Zagreb. [This report could not be located because of insufficient information in the electronic citation. The article title and author names were used in a general internet search and on internet databases, but no results were returned.]

- Tiecco, G. 1965. A search of healthy carriers of *Salmonella* among regularly slaughtered pigs. [This article could not be located because of insufficient information in the electronic citation. The article title and author names were used in a general internet search and on internet databases with no results.]

- Wahlstroem, H., Wierup, M., Olsson, E., and Engvall, A. Prevalence of *Salmonella* in swine, cattle and broilers after slaughter in Sweden. International course on *Salmonella* control in animal production and products arranged by the National Veterinary Institute of Sweden and the World Health Organization, August 1993. A presentation of the Swedish *Salmonella* Programme. Proceedings. Uppsala (Sweden, Statens Veterinaermedicinska Anstalt. April 1994, pp. 141–150. Oeijeberg-Bengtson, S.). [These proceedings could not be found; however, when a general Internet search was conducted, it was discovered that this reference should be on pages 141–150 of a journal, but the journal was requested through Interlibrary Loan and no journal was found.]
on the Ecology of Salmonella in Pork Production; two were found in the Proceedings of the 3rd International Symposium on the Epidemiology and Control of Salmonella in Pork; two were found in the Proceedings of the 6th International Symposium on the Epidemiology and Control of Foodborne Pathogens in Pork; and one was found in the Proceedings of the 20th International Pig Veterinary Society Congress. A further 16 manuscripts that may have had potentially useful information could not be retrieved (Table 1).

Sixteen manuscripts reported data using a design that sampled at more than one processing point, and the characteristics of the manuscripts are presented in Table 2. However, only data from 12 manuscripts were included in the descriptive analyses. Among the four excluded studies, one reported sampling only one or two animals at each processing point, and these data were excluded from the analysis because the estimates of prevalence could only be 0%, 50%, or 100% (Giovannacci et al., 2001). Another study was excluded because, although it reported 0% prevalence at the processing points, the number sampled was not reported (Rho et al., 2001). Two other articles that reported conducting studies that collected at several points along the processing line did not provide results; this is likely because the studies were identified in conference proceedings and the authors may have been reserving the data for later publication (Sørensen et al., 1999; Widders et al., 1996).

These 12 manuscripts reported data from 44 studies, and are included in the box-and-whisker plot (Fig. 1) and descriptive information (Table 3). Figure 1 shows the distribution of Salmonella prevalence for processing points with more than three observations at the following points: bleed, scald, dehair, singe, polish, evisceration, split, stamp, wash, and 18–48 h of chilling. One article reported prevalence after the first and second dehairing machines. We used the data after the second dehairing machine, as it constituted “after dehairing” in such environments (Davies et al., 1999). One article identified by the search was published in 1961 (Kampelmacher et al., 1961). The article assessed the impact of singing, scalding, and mechanical and hand depilation. Although, the hand depilation data was likely not relevant, other information suggested

### Table 2. Descriptive Data About the Slaughter-to-Cooler Studies

<table>
<thead>
<tr>
<th>Reference</th>
<th>Same cohort studied</th>
<th>Country</th>
<th>Pig selection approach</th>
<th>Data included in analyses</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Kampelmacher et al., 1961)</td>
<td>Yes</td>
<td>The Netherlands</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Chau et al., 1977)</td>
<td>No</td>
<td>Hong Kong</td>
<td>Random, method not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Saide-Albornoz et al., 1995)</td>
<td>No discernible</td>
<td>USA</td>
<td>Random, method not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Widders et al., 1996)</td>
<td>No</td>
<td>Australia</td>
<td>Not described</td>
<td>No</td>
</tr>
<tr>
<td>(Davies et al., 1999)</td>
<td>No</td>
<td>UK</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Sørensen et al., 1999)</td>
<td>No</td>
<td>Denmark</td>
<td>Not described</td>
<td>No</td>
</tr>
<tr>
<td>(Giovannacci et al., 2001)</td>
<td>No</td>
<td>France</td>
<td>No described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Quirke et al., 2001)</td>
<td>Yes</td>
<td>Ireland</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Rho et al., 2001)</td>
<td>Yes</td>
<td>Korea</td>
<td>Not described</td>
<td>No</td>
</tr>
<tr>
<td>(Swanenburg et al., 2001)</td>
<td>Yes</td>
<td>The Netherlands</td>
<td>Convenient</td>
<td>Yes</td>
</tr>
<tr>
<td>(Tamplin et al., 2001)</td>
<td>Yes</td>
<td>USA</td>
<td>Convenient</td>
<td>Yes</td>
</tr>
<tr>
<td>(Pearce et al., 2004)</td>
<td>Sometimes</td>
<td>Ireland</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Creus et al., 2005)</td>
<td>Not discernible</td>
<td>Spain</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Keenliside et al., 2005)</td>
<td>Not discernible</td>
<td>Canada</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(De Busser, 2008)</td>
<td>Not discernible</td>
<td>Belgium</td>
<td>Not described</td>
<td>Yes</td>
</tr>
<tr>
<td>(Algino et al., 2009)</td>
<td>Yes</td>
<td>USA</td>
<td>Not described</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**FIG. 1.** Box-and-whisker plot describing the distribution of prevalence estimates of Salmonella-positive samples for studies at each carcass sampling point. Processing points evaluated were stun, bleed, kill, scald, dehair, singe, polish, bung removal, evisceration, split, stamp, final wash, immediately after chill, and 18–48 h after chilling. However, if fewer than three studies evaluated one point, descriptive statistics were not calculated.
the processes used were not strikingly different than current processing approaches. The 1961 article reported using scald temperature of 62°C and a singe of 1–12 s in a cylinder at 1200–1400°C, similar to the processes reported by Pearce et al. (2004), who studied a plant that employed a scald at 61 ± 1°C and a 1200°C singe for 15 s. Therefore, data from this manuscript were considered relevant. One manuscript reported data from 10 small abattoirs, which differed based on wash temperatures and skinning (yes/no). The data were not reported by plant; therefore, we used the combined data as presented for each study in Figure 2. Nineteen point-to-point changes showed an increase in prevalence of Salmonella spp. on the carcasses. These data are identified by the searches. Two manuscripts were available in English that described sampling of pork after chilling at more than one point in a swine abattoir from the same cohort of pigs.

Table 3. Descriptive Statistics for the Population of Salmonella-Positive Samples at Carcass Sampling Points (Slaughter-to-Cooler)

<table>
<thead>
<tr>
<th>Carcass sampling Point</th>
<th>Number of studies</th>
<th>Minimum</th>
<th>25th Quartile</th>
<th>Median</th>
<th>Mean</th>
<th>75th Quartile</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stun</td>
<td>a</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Bleed</td>
<td>20</td>
<td>0.10</td>
<td>0.20</td>
<td>0.32</td>
<td>0.55</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Scald</td>
<td>11</td>
<td>0.04</td>
<td>0.06</td>
<td>0.06</td>
<td>0.17</td>
<td>0.12</td>
<td>0.64</td>
</tr>
<tr>
<td>Dehair</td>
<td>10</td>
<td>0.02</td>
<td>0.09</td>
<td>0.17</td>
<td>0.19</td>
<td>0.29</td>
<td>0.43</td>
</tr>
<tr>
<td>Singe</td>
<td>10</td>
<td>0.00</td>
<td>0.005</td>
<td>0.25%</td>
<td>0.11</td>
<td>0.22</td>
<td>0.40</td>
</tr>
<tr>
<td>Polish</td>
<td>14</td>
<td>0.00</td>
<td>0.00</td>
<td>0.03</td>
<td>0.07</td>
<td>0.10</td>
<td>0.41</td>
</tr>
<tr>
<td>Bung removal</td>
<td>a</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>Eviscerate</td>
<td>7</td>
<td>0.03</td>
<td>0.05</td>
<td>0.07</td>
<td>0.11</td>
<td>0.11</td>
<td>0.32</td>
</tr>
<tr>
<td>Split</td>
<td>7</td>
<td>0.00</td>
<td>0.04</td>
<td>0.11</td>
<td>0.16</td>
<td>0.23</td>
<td>0.45</td>
</tr>
<tr>
<td>Stamping/inspection</td>
<td>3</td>
<td>0.09</td>
<td>0.11</td>
<td>0.13</td>
<td>0.16</td>
<td>0.19</td>
<td>0.26</td>
</tr>
<tr>
<td>Final wash</td>
<td>10</td>
<td>0.00</td>
<td>0.01</td>
<td>0.04</td>
<td>0.11</td>
<td>0.11</td>
<td>0.55</td>
</tr>
<tr>
<td>Immediately post-chill</td>
<td>a</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
18–48 h chilling        | 25                | 0.00    | 0.03          | 0.02   | 0.30 |

*Processing points evaluated were stun, bleed, kill, scald, dehair, singe, polish, bung removal, evisceration, split, stamp, final wash, immediately after chill, and 18–48 h after chilling. However, if fewer than three studies evaluated one point, descriptive statistics were not calculated.

NA, not available.

Results of cooler-to-shipping

For the review of cooler-to-shipping, 999 citations were identified by the searches. Two manuscripts were available in English that described sampling of pork after chilling at more than one point in a swine abattoir from the same cohort of pigs.
Banks and Board, 1983; Giovannacci et al., 2001). Two manuscripts also reported the prevalence of Salmonella spp. on carcases and then at one sampling point in the processing chain after the cooler (Rho et al., 2001; Saide-Albornoz et al., 1995). Extracted information from these four studies is reported in Table 4. None of these studies described the stages of processing employed by the study plants. Given the lack of data, we decided to not pursue this aspect of the review any further.

Discussion

The slaughter-to-cooler review identified 44 studies that evaluated the prevalence of Salmonella on carcases. The aggregated data across the studies suggest that the processes employed from slaughter to the cooler are associated with steady decreases in Salmonella prevalence. This slaughter-to-cooler review provides publicly available empirical evidence for the efficacy of the procedures employed in pork abattoirs to control Salmonella (Fig. 1). The mean and median Salmonella prevalence tended to decrease during processing, even in a variety of settings, providing evidence that the measured processes are robust. This information could be used to convey to the consumer the efficacy of the measures taken to control Salmonella from slaughter to the cooler. It is perhaps not unexpected that evisceration was commonly associated with increases in prevalence, but later steps in the processing line appear to counteract this step. This, therefore, suggests that the evisceration point is the one where new interventions may be developed that could produce substantial impact on Salmonella prevalence of pork carcases.

For the cooler-to-shipping review, insufficient data were available to make reasonable conclusions. This paucity of publicly available information has previously been noted. Berends et al. (1998) noted that information about cutting plants was rare, “practically all of which is published in confidential reports in Dutch or in specialized books of limited circulation” (Berends et al., 1998a). If industry or consumers are interested in a public document that summarizes the ecology of Salmonella post-chilling in pork, then more data availability is needed.

It is important to note several potential biases in this review. First, it was noted that what seemed like a large number of potentially relevant publications in this review were excluded because of the inability to obtain a full copy of the manuscript. We traditionally have not kept track of studies that could not be found, and similar data is not published in other reviews. However, it is noteworthy that we found 16 relevant publications, and there existed equally as many potentially relevant publications that could not be found despite significant search attempts. Obviously, it is unclear whether their results are relevant, or if they would change the inferences from the quoted manuscripts.

Second, a large number of non-English articles were identified by the search, but we were unable to consider these results due to lack of funds for translation. In the cooler-to-shipping review, 999 articles were identified as potentially relevant after the first level screening, and 461 (46%) were excluded because the manuscript was not available in English. It is not possible to conclude whether the non-English articles were truly relevant to the review or not. However, we
<table>
<thead>
<tr>
<th>Study</th>
<th>Study plants</th>
<th>Year</th>
<th>Country</th>
<th>Sample</th>
<th>Specimen size</th>
<th>Number of replicates per sample</th>
<th>Salmonella spp. positive samples/samples tested (positive percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Banks and Board, 1983)</td>
<td>1</td>
<td>1980–1981</td>
<td>UK</td>
<td>Linked sausages</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>13/20 (65%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lean pork</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>6/15 (40%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Belly meats</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>7/20 (35%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Head meats</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>2/20 (10%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Semi-lean meats</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>7/20 (35%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Rinds</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>6/20 (30%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Back fat</td>
<td>1 kg</td>
<td>5 replicates each of 60 grams</td>
<td>0/ND (0%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Salmonella spp.- positive samples/samples tested (positive percent)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Giovannacci et al., 2001)</td>
<td>2 plants (600 and 800 pigs per hour)</td>
<td>ND</td>
<td>France</td>
<td>Carcasses after 1st chilling</td>
<td>Pooled samples from swabs of 5 carcasses (swabbing 20*20 cm² area for each)</td>
<td>1 cotton swabs for 5 carcasses</td>
<td>7/8 (87.5%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Carcasses during refrigeration before cutting</td>
<td>Pooled samples from swabs of 5 carcasses (swabbing 20*20 cm² area for each)</td>
<td>1 cotton swabs for 5 carcasses</td>
<td>6/8 (75%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Raw ham</td>
<td>25 cm² on 10 different units</td>
<td>5 samples of 0.5-mm squares for each unit and 10 units</td>
<td>4/8 (50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Deboned and defatted shoulders</td>
<td>25 cm² on 10 different units</td>
<td>ND</td>
<td>1/8 (12.5%)</td>
</tr>
<tr>
<td>(Rho et al., 2001)</td>
<td>6 plants (capacity not described)</td>
<td>ND</td>
<td>Korea</td>
<td>Carcasses in cooler</td>
<td>Swabs</td>
<td>0/ND (0%)</td>
<td></td>
</tr>
<tr>
<td>(Saide-Albornoz et al., 1995)</td>
<td>3 plants (~1000 per hour)</td>
<td>ND</td>
<td>USA</td>
<td>Carcasses in cooler</td>
<td>Swabs of dorsal size of ham and midpoint of loin</td>
<td>Not applicable</td>
<td>1/270 (0.4%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Boneless loins</td>
<td>Ventral side, prior to packaging</td>
<td>Not applicable</td>
<td>1/135 (0.7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Boneless loins</td>
<td>36 days of storage at 2°C</td>
<td>Not applicable</td>
<td>0/45 (0.0%)</td>
</tr>
</tbody>
</table>

ND, not determined.
Entry 3

Third, the use of a diverse group of studies that reflect variation in processing practices may be another issue, which may be considered a strength or weakness. If the unit of concern were the particular plant, then the approach employed is a weakness. However, our aim was to provide an overall summary of how systems work by using available empirical data; therefore, the diversity is a strength. Additional data or studies containing more sampling points would strengthen the review inferences; however, these were not available. An alternative approach would be to model the system; however, this has already been done. Our aim was to document the processing system using a different approach. Alban and Stark (2005) modeled the swine processing system, utilizing “author best guess” or a single article as the parameter estimate. The data we provide here may actually be used to parameterize risk assessments because it comprehensively summarizes available data.

Fourth, as mentioned previously, the sensitivity and specificity of the culture methods varied between studies. We chose to use paired data within the plants as an indirect method of adjusting for these differences. For example, a method with low sensitivity would have the same low sensitivity at all processing points in the plant therefore correctly capturing the trend, if not the magnitude, of Salmonella prevalence change (i.e., increasing, decreasing, or remaining stable). If the manuscripts had reported the sensitivity of employed culture methods, a transformation from apparent prevalence to a true prevalence would have provided a more direct adjustment.

Finally, we did not calculate a sample size-based weighted average for the prevalence of Salmonella at each processing point or attempt to calculate a regression slope to describe the change in prevalence from bleed to chill because some studies failed to provide a numerical sample size for each sampling point; therefore, we were limited to describing the quartiles of carcasses positive for Salmonella. The variation of percentage of carcasses positive for Salmonella is likely of greater public health relevance than quartile analyses. We hypothesize that studies that were conducted but reported 0% at all points would be considered less interesting and therefore less likely to be published. Such a bias would mean that overall means would be biased upwards—hence, our preference for reporting descriptive information. Equally, it might be argued that the selected sample size or testing methodology was insufficient for task, and therefore had nothing to add.

**Conclusion**

The aggregated data across the 16 studies suggest that the processes employed in abattoirs from slaughter to the cooler are associated with steady decreases in Salmonella prevalence. Evisceration was commonly associated with increases in prevalence, but later steps in the processing line appear to mitigate this effect. Therefore, evisceration is a point in the processing point where development of effective new interventions would have a substantial effect of Salmonella on pork carcasses. This information could be used to convey, to consumers, the effectiveness of the measures taken to control Salmonella from slaughter to the cooler, and to prioritize future research efforts.

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**Disclosure Statement**

No competing financial interests exist.

**References**


De Busser EV, Mase D, Dewail J. Salmonella contamination rate along the slaughter line in five different Belgian slaughterhouses. Presented at the International Pig Veterinary Society Congress, 2008.


Note that Berands et al. (1998b) did use two Dutch language articles that may have been relevant.


Tamplin ML, Feder I, Palumbo SA, Oser A, Yoder L, Luchansky JB. *Salmonella* spp. and *Escherichia coli* biotype I on swine carcasses processed under the hazard analysis and critical control point-based inspection models project. *J Food Prot* 2001;64:1305–1308.


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