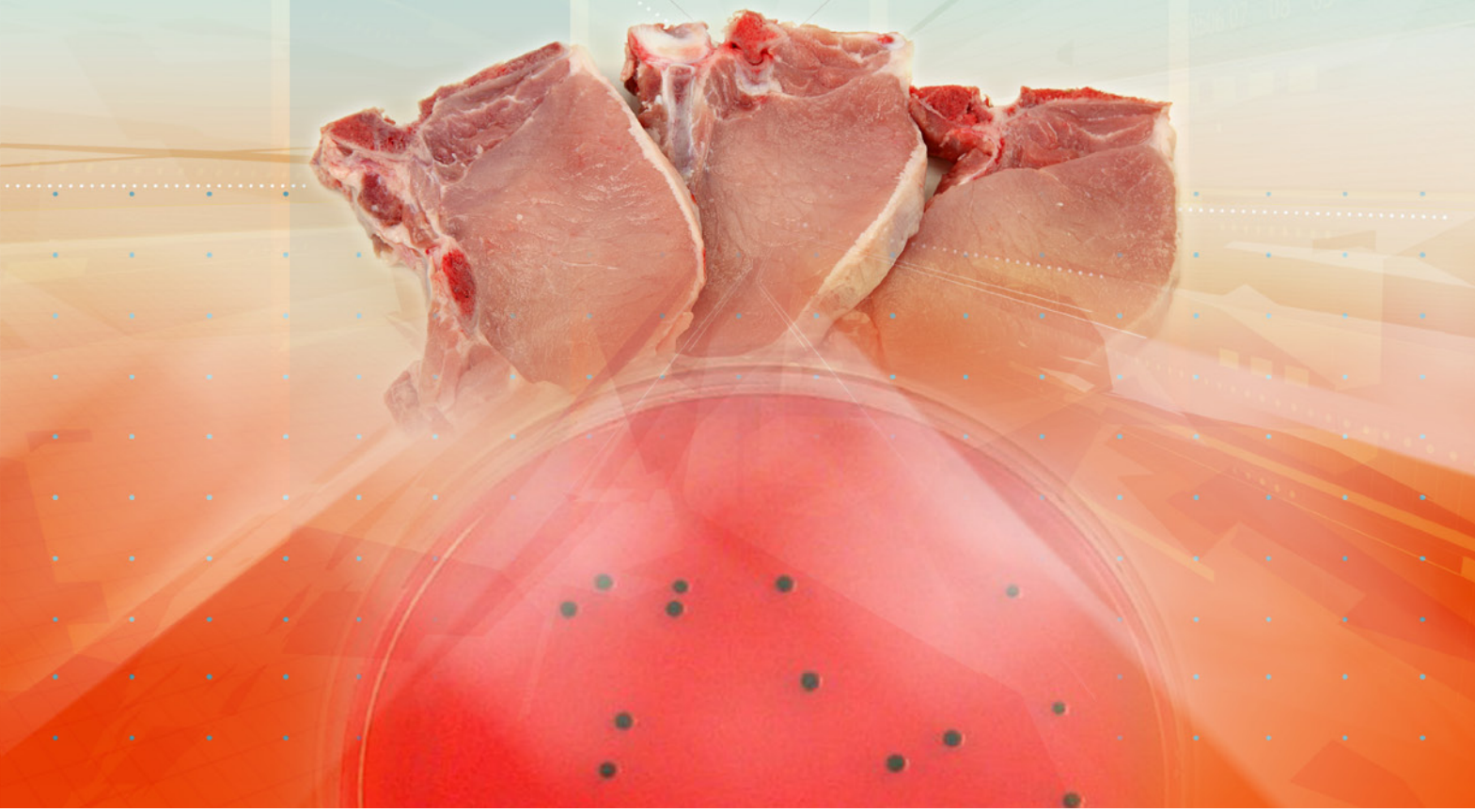
Salmonella in pork on the island of Ireland:

A microbial risk assessment



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Executive Summary

A study was carried out on the occurrence of *Salmonella* on pork on the island of Ireland and an assessment of the risk factors contributing to its transmission. It included microbiological studies to track the *Salmonella* status of individual pigs through the pork chain from farm to primal cuts. Studies on the *Salmonella* status of pork cuts in boning hall, and on raw pork cuts at retail were also undertaken. A quantitative microbial risk assessment model was developed for *Salmonella* on pork cuts covering the chain from slaughter to boned-out cuts.

Prevalence and transmission of *Salmonella* in the pork chain

Salmonella on pork cuts in boning halls

Salmonella spp. were recovered from 24 of 720 (3.3%) pork cuts sampled in boning halls of pork abattoirs in the Republic of Ireland (ROI) and from 44 of 525 (8.38%) pork cuts in Northern Ireland (NI). The difference in prevalence is not statistically significant between jurisdictions. The key finding was the enormous variation in *Salmonella* prevalence on different sampling days, 0 to 31.6% in ROI and 0 to 52.5 % in NI. In both jurisdictions, the prevalence and numbers of *Salmonella* on pork cuts was significantly higher on cuts taken during the afternoon production than the morning production. *Enterobacteriaceae* levels also increased over the course of the day. Genetic fingerprinting showed the same *Salmonella* isolates on equipment and cutting surfaces in the boning hall and on pork cuts taken on the same day; indicating the role of cross contamination in transmission of the pathogen. On particular days of operation, it was shown that the same *Salmonella* strain could persist on cutting equipment and surfaces throughout the day contaminating large volumes of pork. On days that *Salmonella* prevalence was high, *Enterobacteriaceae* counts were also generally high indicating breakdowns in hygiene and that monitoring this group of microorganisms could be useful in controlling *Salmonella*. A better understanding of variability in the prevalence of *Salmonella* between factories and on different production days was considered essential in reducing overall risk.

Salmonella on pork cuts at retail

The mean prevalence (%) of *Salmonella* on pork samples taken in butcher shops and supermarkets in ROI was 13/500 (2.60%) while the overall *Salmonella* prevalence in NI was 11/200 (5.5%). In both jurisdictions, the key finding again was the enormous variation in *Salmonella* prevalence on different sampling days. Genetic fingerprinting showed evidence of cross contamination of *Salmonella* between samples. The prevalence of *Salmonella* on pork samples was associated with higher *Enterobacteriaceae* counts, highlighting the impact of hygiene in pathogen control at retail level.

Tracking Salmonella through the pork chain

In ROI, the *Salmonella* status of pigs from selected herds of different historical serological categories (as determined by regulatory programme) was tracked from the farm through transport (before and after loading pigs and after

washing of trucks) and lairage (before and after pigs entered). After slaughter each individual pig was tested for *Salmonella* by examination of caecal contents, rectal faeces, carcass swabs (before washing and chilling, and after chilling) and pork primal cuts. In NI, a smaller tracking study on the *Salmonella* status of individual pigs at the slaughter stage was conducted. Overall, the study showed that transport of pigs in contaminated trucks has the potential to allow *Salmonella* negative pigs to become infected. Cold power washing of trucks was inadequate at removing *Salmonella* and, in some cases, trucks were more widely contaminated after washing. The lairage areas were often highly contaminated with *Salmonella* spp., posing a risk for incoming negative pigs particulary for Category 1 herds. In Category 3 herds, *Salmonella* was present in the caecal contents of 45% of pigs and 95% of the *Salmonella* they carried were traced back to the farm of origin. In Category 1 herds, *Salmonella* was present in 16% of pig caecal contents and 71% of these *Salmonella* were traced back to the lairage. From Category 2 herds, 72% of animals were caecally positive for *Salmonella*. The study highlighted that there is in general, no correlation between the historical *Salmonella* serological herd Category and actual bacteriological status of an individual pig at the time of slaughter.

Tracking and genetic fingerprinting of *Salmonella* recovered from the pork chain showed that contamination of carcasses and pork cuts could be introduced from the pig's own caecal or rectal contents (faeces) during slaughter and dressing. Contamination often occurred from other pigs during transport, lairage, or contact with contaminated pork cuts, equipment, surfaces etc during processing and distribution. Cross contamination within the slaughter plant environment accounted for up to 69% of contamination on carcasses and pork cuts. However, while cross contamination was shown to potentially occur at many different stages in the chain, it was intermittent and variable. There were very clear differences in the prevalence of *Salmonella* between different factories, and between different days of slaughter. This was evident in both ROI and NI plants.

S. Typhiumuium (~50%) and S. Derby (~20 %) were the dominant isolates recovered from pork but many others serotypes were also recovered and most of these isolates were antibiotic resistant, indicating that they would be difficult to treat clinically.

Risk assessment model

The risk model was created in Excel with the add-on package @Risk™ (Pallisade Corporation, New York, USA) and followed the chain from where pigs were presented for slaughter through to boned-out pork cuts.

Data inputs and assumptions

Initial data inputs to the model on the prevalence of *Salmonella* in pigs presented for slaughter were based on microbiological surveys of the pathogen in caecal contents at slaughter. The model output for prevalence of *Salmonella* on boned-out pork cuts was validated using microbiological surveillance data for *Salmonella* on pork cuts in the boning halls of slaughter plants in ROI and NI.

The model assumed that caecal contents contaminated with *Salmonella* were sources of cross contamination to carcasses and a cross contamination factor was created based on surveillance data for the pathogen in pig caecal

contents and on carcasses (Duggan *et al.,* 2009, Casey *et al.,* 2004, Quirke *et al.,* 2001, unpublished data from UCD (1999 to 2001) and data on *Salmonella* on eviscerated pork carcasses (Duggan et al, 2009; Sorensen *et al.,* 2004; Kranker *et al.,* 2003; Quirke et al. 2001; Davies *et al.,* 1999; Morgan *et al.,* 1987 and Oosterom *et al.,* 1985). The correlation between these two sets of data was r^2=0.77. The impact of carcass dressing operations, including evisceration, washing, chilling, and cross contamination in the boning hall on *Salmonella* numbers on contaminated carcasses were estimated based on research studies in the literature on the impact of these operations on the pathogen.

Model outputs

The model estimated that *Salmonella* prevalence on pork cuts from ROI boning halls was on average 3.9% (95% CI 1.6-8.2%). This output was validated against a microbiological survey of *Salmonella* on pork cuts in ROI abattoirs (mean 3.3%; 95% CI 2.0-4.6%) carried out in commercial pork abattoirs as part of this research project, which indicates that the level of contamination predicted by the model and the actual survey results were similar.

Using NI data for *Salmonella* caecal carriage based on a study by McDowell *et al.,* (2007), the simulation model estimated that the *Salmonella* prevalence on pork cuts produced in NI was on average 4.5% with a 95% CI of 0.33-12.65%

Analysis of the risk model (by rank order correlation sensitivity analysis) indicated that the final rinsing and chilling are critical points that are very efficient in reducing the occurrence of *Salmonella* on the final product. It also indicated a linear correlation between the prevalence of *Salmonella* in caecal contents and on pork cuts.

The research indicated a need to implement measures to reduce cross contamination during transport, lairage, processing and at retail level. An understanding of why there is such variability in cross contamination and prevalence of *Salmonella* between factories and on different production days would greatly assist in reducing overall risk.

Expert Elicitation

An expert elicitation study was conducted to rank a series of potential management interventions in terms of effectiveness and therefore provide recommendations on which interventions would be most effective. It was not the intention of the study to guarantee that such interventions would be effective for all stakeholders; the success of each intervention will depend on a number of factors, as is evident from the main barriers impacting the success of interventions in practice, which were identified in this study.

The expert study indicated that the most effective interventions at the on-farm stage of the pork supply chain are likely to be (1) Good Agricultural Practices (GAP) and hygiene measures with all in/all out policies, (2) appropriate feed and (3) education and awareness. However barriers to the success of these include the costs involved in implementing GAP and hygiene measures in practice, high feed costs and resistance of people to change.

At the lairage stage the potential control strategies indicated by the expert group included (1) minimising the amount of time that pigs spend in the lairage prior to entering the slaughterhouse (2) improved cleaning of the

lairage to reduce/prevent cross contamination (3) separating herds from different farms and separating different Category herds through to slaughtering. Potential barriers to their success included just-in-time delivery difficulties which may impact on holding times of pigs in the lairage and cost associated with additional cleaning and changing current lairage designs.
At the stage of slaughtering/processing, the top rated interventions recommended were (1) careful evisceration (2) bagging the bung and (3) logistic slaughter. The main barrier impacting on the success of careful evisceration and bagging the bung is poor employee training. Issues regarding pig herd Categorisation (with poor correlation between the historical serological status and the actual *Salmonella* bacteriological status for individual animals at the time of slaughter as shown in this study) can act as a barrier to success of logistic slaughter in practice.

At the final distribution/retail/catering/consumer stage it was identified that consumer education regarding the risks from cross contamination as 'a step in the risk reduction process' and that educating workers regarding the risks from cross contamination was considered an effective intervention that has the potential to ultimately reduce the risk of cross contamination incidents. However, ineffective and/or insufficient training can act as a major barrier.

In conclusion, *Salmonella* has the potential to enter and spread at all stages of the pork supply chain and therefore control must involve a farm to fork approach. A general consensus among the expert group was that the utilisation of a combination of interventions is imperative; with no single intervention likely to have an impact in isolation. There are many potential barriers impacting the success of interventions in practice and that cost and safety will always be comprised against each other. This highlights the need to combine risk modelling (which can predict risk reduction) with cost benefit analysis for potential interventions.

Overall conclusions

This present study observed that pigs presented for slaughter on the island of Ireland are frequently infected with *Salmonella*. During the slaughter process the pathogen can be transferred to the meat. Categorising the pig herd based on a historical serological testing for the presence of *Salmonella* was not shown to be a good predictor of the bacteriological *Salmonella* status of individual pigs at the time of slaughter. However, it is acknowledged that serological testing does help in giving a rough estimate of the overall *Salmonella* status of a pig herd and the risk model showed a linear correlation between prevalence of *Salmonella* in caecal contents and on pork cuts at factory level. Therefore if the number of herds presented for slaughter with high levels of *Salmonella* (Category 3) was reduced, there would be less potential for contamination of the lairage, equipment etc and so less *Salmonella* contamination on pork. The impact of cross contamination during transport, lairage, processing and distribution cannot be ignored and measures to reduce this would significantly reduce the dissemination of *Salmonella* in the chain and the risk posed.

Contents

1. Introduction

1.1 Salmonella

Salmonella spp. are responsible for many cases of human illness and in most developed countries including the island of Ireland, it is the second most common cause of bacterial gastro-intestinal illness. The major sources for human salmonellosis are farm animals/poultry which may be intestinal carriers of the organism. *Salmonella* can be shed in the faecal material and transmitted to humans via direct contact with the contaminated faecal material or indirectly via faecal contamination of food or water. Symptoms of *Salmonella* infection usually appear 12–72 hours after infection, and include fever, abdominal pain, diarrhoea, nausea and occasionally vomiting. The illness usually lasts 4–7 days, and most people recover without treatment. However, in some people, especially the elderly, infants, and those with impaired immune systems, the illness may be so severe that the patient needs to be hospitalised. On the island of Ireland, salmonellosis is primarily linked to two serotypes, S. Enteriditis and *S.* Typhimurium (Foley *et al.* 2007). Since 2000 the number of clinical cases of salmonellosis in ROI has ranged from 16 cases per 100,000 (in 2000) to 8.9 cases per 100,000 in 2005 (www.HPSC.ie) while in NI the number of cases ranged from approximately 10 to 28 cases per 100,000 between 2000 and 2007 (CDSC, NI).

1.2 Salmonella in pork

There are several routes of transmission for salmonellosis, but the majority of human infections are generally transmitted to humans through consumption of contaminated food of animal origin. Contaminated pork, and derived products, have been implicated in a number of human salmonellosis cases (Table 1). *S.* Typhimurium is the predominant serotype isolated from humans in Europe and pigs are an important reservoir of this particular serotype (Boyen *et al.* 2008)

Table 1. Summary of selected outbreaks of *Salmonella* attributed to contaminated pork

Location	No. of cases	No. of deaths	Implicated food source	Reference
Multi-country	163	1	Pork	ECDC, 2008
USA	67	0	Pulled pork	Clark, 2007
Italy	63	0	Pork salami	Luzzi et al, 2007
Germany	115	0	Raw minced pork	Jansen *et al.* 2005
Ireland	78	0	Ham	Epi-insight, 2001
Japan	105	0	Roast pork	Murase *et al.* 2000
Denmark	550	0	Pork	Bager *et al.* 1995

Pigs are asymptomatic carriers of *Salmonella* and the pathogen can be found in their entire digestive tracts and connected lymphatic tissues. An overview of carriage of *Salmonella* in pig caeca and faeces is shown in Table 2.

Table 2. Overview of prevalence data of *Salmonella* spp. pig faeces/caecum

Country	Farm/ Abattoir	Sample Type	Sample Number	*Salmonella* Positive (%)	Reference
Japan	Farm	Faeces	5393	3.2	Kishima *et al.* 2008
USA	Abattoir & Farm	Faeces	129	57.4	Hurd *et al.* 2004
Belgium	Abattoir	Faeces	345	19.0	Botteldoorn *et al.* 2003
Northern Ireland	Abattoir	Caecal	513	31.4	McDowell *et al.* 2007
UK	Abattoir	Caecal	2509	23.0	Davies *et al.* 2004
USA	Abattoir	Faeces	1334	14.3	Rajic and Keenliside, 2001
Canada	Abattoir	Caecal	1420	5.2	Letellier *et al.* 2001
Denmark	Farm	Faeces	135	37.0	Stege *et al.* 2000
Germany	Abattoir	Faeces	830	7.0	Gareis *et al.* 1996
Hungary	Abattoir	Faeces	200	48.0	Jayarao *et al.* 1989

Boughton *et al.* (2004) recovered *Salmonella* spp. from 2.9% (27/921) of raw pork sausages (prepacked and loose) between 2001 and 2002. Jordan *et al.* (2006) reported *Salmonella* spp. in raw pork samples for 2002, 2003 and 2004 at prevalence's of 2.3% (160/6823), 2.0% (136/6638) and 2.1% (158/7683), respectively. There remains, however, limited quantitative data on *Salmonella* spp. on pork at retail, which is required for quantitative microbial risk assessment (QMRA) models and the development of strategies to reduce risk from this pathogen /commodity.

EU microbiological criteria (EC 2073/2005) state that minced pork or pork preparations intended for human consumption must meet EU food safety criteria with absence of *Salmonella* in 25g if intended to be eaten raw or 10g if intended to be eaten cooked.

In order to manage *Salmonella* infection in pigs, many countries including ROI and NI, introduced monitoring and control programmes at herd level in the early 2000's. At the time of print, in ROI there is a regulatory programme for serological monitoring of *Salmonella* in herds which is administered by the Central Veterinary Research Laboratory (CVRL), Department of Agriculture, Fisheries and Food, using a serological test. Twenty four pigs from each herd are tested three times a year at slaughter plants and herds are assigned a Category (1-3) based on a calculated weighted average of the three most recent tests. A certificate is issued grading the herd as Category 1 (< 10% positive), Category 2 (≥ 10%, ≤ 50% positive), or Category 3 (> 50% positive). At slaughter, pigs from Category 3 herds are slaughtered separately from other pigs and in a manner that minimises the risk of cross contamination. The head meat and offal of Category 3 pigs may not be sold in the raw state and must be either heat-treated in an approved manner before being passed fit for human consumption, or destroyed. Pigs with no valid Category certificate are treated as Category 3 in slaughter plants. The programme is currently under review.

Up until mid 2008, when this research study took place NI adhered to the voluntary scheme put in place by the Meat and Livestock Commission which relies on serological testing. This Zoonosis Action Plan (ZAP) for *Salmonella* scheme was funded by BPEX (body representing pig levy payers in England) and the Food Standards Agency. It was based upon a scheme that has been operating in Denmark for several years. Every farm was sampled on a quarterly basis and the proportion of pigs giving a positive result compared to the national average. Those in the highest Category were allocated to ZAP Level 3, the next group into ZAP Level 2 and the remainder were ZAP Level 1. Farms in Level 3 were provided with specialist advice on measures to control *Salmonella* on-farm. In addition, an advice pack prepared by BPEX, DEFRA (Department of Environment, food and rural affairs) and the VLA (Veterinary Laboratory Agency) was available to all farms in Levels 2 and 3. In April 2008, the ZAP scheme was replaced by the Zoonoses National Control Programme for *Salmonella* in pigs, focusing on a whole chain risk-based approach to tackling *Salmonella* Progress on reducing the risk to the consumer from *Salmonella* in pig meat will be monitored through measuring the prevalence on carcases in abattoirs (http://www.food.gov.uk/foodindustry/farmingfood/salmonellainpigs/).

1.3 Risk analysis

Risk analysis is a useful tool for the management of food safety risks and can be used to evaluate the level of exposure to a potential hazard and subsequently the risk to human health and is comprised of three elements: risk assessment, risk management and risk communication.

Risk assessment as defined by Codex Alimentarius Commission is a scientifically-based process in which hazards and risk factors are identified and the risk posed by the agent is calculated. The definition includes quantitative risk assessment, which emphasises reliance on numerical expressions of risk, and also qualitative expressions of risk, as well as an indication of the attendant uncertainties. It consists of (a) hazard identification; (b) hazard characterisation; (c) exposure assessment; and (d) risk characterisation. Apart from an end point calculation of risk, the risk model developed can be of value in determining the parts of the chain which contribute most to risk; in identifying the critical control points for (Hazard Analysis Critical Control Point (HACCP)) systems, or to investigate the effect of changes in practices or procedures throughout the chain on the risk posed.

Risk management is an evaluation of the acceptability of the risk posed and the implementation of measures to reduce this risk, if necessary. The four components of risk management frameworks can be summarised into: preliminary risk management activities, evaluation of risk management options, implementation of the risk management decisions and monitoring and review.

Risk communication is an interactive process of exchange of information and opinion on risk among risk assessors, risk managers, and other interested parties. It involves transparent communication between the

risk assessors (scientists) and the risk managers (regulators, industry, government agencies etc.). Decisions on risk communication, including what, whom and how should be part of an overall risk communication strategy.

The full risk analysis process with a risk assessment model linked directly to risk management and communication potentially has a very valuable role in the strategic management of *Salmonella* in pork on the island of Ireland.

2. Objectives and scope of the study

Recognising the public health problem related to *Salmonella* and the potential role of pork in its transmission, a research programme was funded by safefood and the Department of Agriculture, Fisheries and Food through the Food Institutional Research Measure (FIRM). This work was conducted by Ashtown Food Research Centre, Teagasc; University College Dublin, Queens University, Belfast and the University of Ulster, Coleraine, on the occurrence of *Salmonella* on pork on the island of Ireland and an assessment of the risk factors contributing to its transmission. It included (1) microbiological studies on the *Salmonella* status of pork cuts at boning hall stage and on raw pork cuts at retail level (2) tracking the *Salmonella* status of individual pigs through the pork chain from farm to primal cuts (3) development of a a quantitative microbial risk assessment (QMRA) model for *Salmonella* on pork, covering the chain from when pigs were presented for slaughter through to boned-out cuts.

2.1 Risk Management Questions

Alongside the scientific team, a risk management forum was convened representing key stakeholders from the pork slaughter and processing sector, retail sector, public health, regulatory authorities and the food safety agencies from the island of Ireland. At the outset of the programme, the risk managers set out the questions which they wished the scientific risk assessment to answer; they are listed as follows:

1. Is there a difference in consumer exposure to *Salmonella* via consumption of pork produced in the two jurisdictions?
2. Is there a relationship between the prevalence of *Salmonella* in the herd and the *Salmonella* status of pork cuts?
3. At pork slaughter, what is the contribution of processing to pork contamination?

3. Prevalence and transmission of *salmonella* in pork

3.1 Salmonella status of pork cuts in the boning hall

A study was carried out to establish the prevalence and numbers of *Salmonella* on pork cuts produced in ROI and the prevalence in NI.

ROI: *Sampling Protocol and analysis*

Samples of pork (n = 720) were taken at random from trays in the boning halls of four commercial pork abattoirs during 12 visits between October 2005 and July 2006. Abattoirs A and B had a high throughput of between 1,500 and 2,000 animals per day and abattoirs C and D had lower throughputs of approximately 800 to 900 per day. In each abattoir animals were progressed from lairage, through stunning, exsanguination, scalding, dehairing, singeing, polishing, evisceration, carcass splitting, weighing and washing following by chilling and boning. The on-line dressing procedures were the same in abattoirs A, B and C as these abattoirs had a linear rail, slaughter, dressing and chilling systems on a single floor. However, abattoir D had a rail on two floors, in which animals moved from the lairage on a lower level [level 0], up to a higher level slaughter and dressing line [level 1], with carcasses moving down to chill storage on level 0 after carcass washing.

The samples taken in each plant were the oyster cut (Figure 1) which remained on the leg in abattoirs A, B and D and on the loin in abattoir C. To ensure that the samples taken were representative of all production times, the day of sampling and the time in the production shifts at which samples were taken was randomised. In each abattoir, a total of sixty samples were taken over the entire working day. Sampling started two hours after a shift had commenced. Thirty samples were taken in the morning and a further thirty in the afternoon. In addition, environmental swabs were taken from equipment in the boning hall in the morning and afternoon.

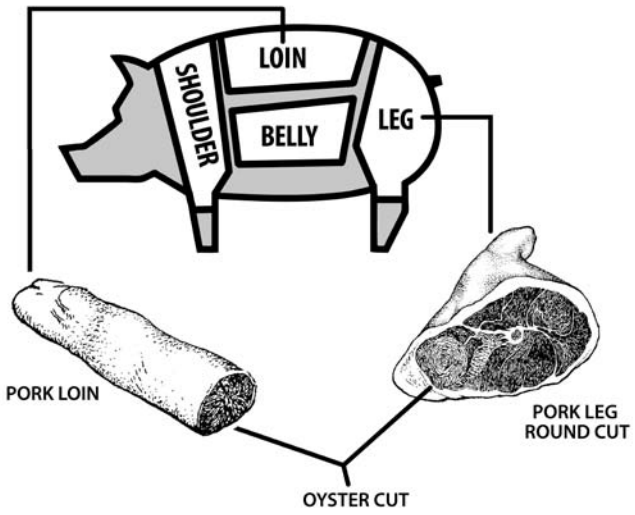

Figure 1. Oyster cut on pork loin and leg after processing

A 25-50 g sample was aseptically excised from the oyster cut and the method used for the isolation, detection and enumeration of *Salmonella* spp. was a PCR screening method with cultural isolation of any suspect positive samples. These methods are described in detail by Prendergast *et al.,* 2008 and Boughton *et al.,* 2004. All confirmed *Salmonella* spp. were serotyped and phage typed as appropriate by The National *Salmonella* Reference Laboratory, University College Hospital, Galway.

Enterobacteriaceae data on pork samples in abattoirs A, B and C were obtained on two sampling days (Days 2 and 3) and in abattoir D data was collected on all three sampling days. *Enterobacteriaceae* data from swabs of equipment and meat contact surfaces were taken in abattoir A on Day 3, in abattoirs B and C on Days 2 and 3 and in abattoir D on all three sampling days. All samples were analysed for *Enterobacteriaceae* using the method described in the British Standards BS 5763 part 10:1993.

NI: *Sampling Protocol and analysis*

Initial discussions with local abattoirs revealed that approximately 50% of pigs slaughtered in NI were imported from ROI. Sampling was thus designed to ensure pork samples were only taken from animals produced in NI, although from lines that ROI pigs may have recently passed along. Samples of pork (n=525) were taken at random from trays in the boning halls of two commercial abattoirs (Plant E, n = 405; Plant F, n= 120) over a total of 15 visits between October 2005 and July 2006.

Abattoir E is the largest pig processing abattoir in NI processing over half of all the province's available pigs and handles approximately 20,000 pigs per week. Abattoir E is one of only two meat processing plants in the UK that has United States Department of Agriculture (USDA) approval which allows them to export their produce to the USA. As carcasses enter the chill they are graded according to fat content, and the origin of the pigs becomes irrelevant. There is potential for cross contamination at this stage between carcasses from derived from pigs that originated in ROI and NI.

Abattoir F is a smaller abattoir processing approximately 5,000 pigs per week. All farms supplying abattoir F are members of the nationally recognised Farm Assured British Pigs scheme. Approximately half of the pigs slaughtered in the abattoir are from ROI. However, ROI and NI pigs are generally processed on different days, which vary each week. Sampling was arranged in advance to ensure that on the sampling day, they were processing only pigs that originated in NI.

Sampling rates were 40 samples per day at plant E and 30 samples per day at plant F, with half of the samples taken in the morning, and half in the afternoon, at both plants. The pork cut taken in each plant was the oyster cut as per Figure 1 above. In abattoir E the oyster region was excised on the boning hall line for further processing, hence this piece was selected from bins for analysis in the lab. In abattoir F the meat remained on the leg, and an excised section of the leg was taken and transported to the lab where the oyster region

was aseptically excised. To ensure that the samples taken were representative, the day and time of sampling in production shifts were randomised.

At abattoir E trim from the oyster cut (25-50 g) was removed while in abattoir F, a section of the leg containing the oyster region was sampled and the oyster trim was removed aseptically at the laboratory. 25 ±0.5g samples of pork were examined as outlined in ISO 6579 but with enrichment in Rappaport Vassiliadis soya broth (RVS: Oxoid, CM 0866) only, as a selective enrichment step. All confirmed *Salmonella* spp. were serotyped by the NI Reference Laboratory for *Salmonella* in Belfast.

Results: **ROI**

The mean prevalence (%) of *Salmonella* spp. on the pork oyster cut in the boning halls of four commercial pork abattoirs during each visit in ROI is shown in Table 3. *Salmonella* was found on 24 / 720 (3.3%) samples. The confidence limit for this data set calculated at the 95% confidence limit was (2.02 to 4.64%).

A key finding from this study was the considerable variation in the mean prevalence of *Salmonella* on different sampling days ranging from 0 to as high as 31.6% over 12 visits. On 9 of the 12 visits no *Salmonella* was detected while on other 3 visits mean daily prevalences of 1.6%, 6.6% and 31.6% were recorded. Analysis of the data using the Chi-square test revealed significant differences in the prevalence of *Salmonella* between the four abattoirs ($P<0.001$).

The calculated MPN values from the *Salmonella* positive samples in abattoirs B and D, corresponding *Enterobacteriaceae* counts and profile of the *Salmonella* isolates are outlined in Table 4. The results of equipment/ environmental swabs tested for *Salmonella* in each abattoir is presented in Table 5. This study observed a direct association between *Salmonella* on pork cuts and on equipment and surfaces in the meat cutting rooms of commercial pork abattoirs. Genetic fingerprinting (pulsed field gel electrophoresis, PFGE) of the recovered isolates sub-typing indicated that on specific sampling days the same isolate was recovered on both pork and environmental samples, demonstrating that cross contamination was responsible for substantial dissemination of *Salmonella* during production. Additionally, a higher level of environmental contamination was noted on some occasions in the afternoon compared with the morning. On another sampling occasion it was noted that the fat trimmer and the table where the spinal column was cut was positive during the morning but not for the afternoon sampling. However, between morning and afternoon sampling in abattoir D it was noted that all cutting surfaces and equipment were sprayed with Quatrol T (Water Technology Limited, Cork, Ireland) at food grade dilution (25 ppm). This is a powerful bactericide based on quaternary ammonium salt (alkyl dimethyl benzyl ammonium chloride), water conditioning agents, alkali donating and pH buffering inorganic builders. This suggests that the use of a sanitising step during processing is beneficial. High *Enterobacteriaceae* counts on particular sampling days suggest hygiene failures during the visits, and these mirrored the prevalence rates recorded for *Salmonella* on pork cuts and in environmental samples.

Table 3. Prevalence (%). of *Salmonella* spp. on pork (oyster cut) in the boning halls of four commercial pork abattoirs in ROI during morning (a.m.) and afternoon (p.m) sampling.

Abattoir	Number tested			Number positive (%)		
	a.m.	p.m.	Total	a.m.	p.m.	Total
A	30	30	60	0	0	0
A	30	30	60	0	0	0
A	30	30	60	0	0	0
B	30	30	60	0	0	0
B	30	30	60	1 (3.3)	3 (10)	4 (6.6)
B	30	30	60	0	0	0
C	30	30	60	0	0	0
C	30	30	60	0	0	0
C	30	30	60	0	0	0
D	30	30	60	9 (30)	10 (33.3)	19 (31.6)
D	30	30	60	1 (3.3)	0	1 (1.6)
D	30	30	60	0	0	0
Total	**360**	**360**	**720**	**11 (3.06)**	**13 (3.61)**	**24 (3.3)**

Taken from Prendergast *et al.,* 2008

In abattoir D, *Enterobacteriaceae* numbers on visit 1 were as high as 5.30 $\log_{10}$ CFU g^{-}_{1}. Such high counts on pork cuts after chilling during particular sampling days are a possible indication of poor hygiene resulting in a build up of contamination on surfaces and equipment in the meat cutting room.

Table 4. Characteristics and numbers of *Salmonella* (MPN g^{-1}) and *Enterobacteriaceae* (log_{10} CFU g^{-1}) on pork from four commercial abattoirs in ROI (adapted from Prendergast *et al,* 2008)

Plant	Visit	Time	Serotype	Phage type	Antibiotic resistance	MPN g^{-1}	Enterobacteriaceae log_{10} CFU g^{-1}
B	2	a.m.	*S.* Derby	-	TMn	< 0.30	2.48
B	2	p.m.	*S.* Livingstone	-	None	<0.30	1.56
B	2	p.m.	*S.* Derby	-	TMn	<0.30	2.28
B	2	p.m.	*S.* Derby	-	TMn	<0.30	1.83
D	1	a.m.	*S.* Typhimurium	U310	None*	0.36	5.08
D	1	a.m.	*S.* Typhimurium	U310	None	<0.30	4.13
D	1	a.m.	*S.* Typhimurium	U310	None	0.36	4.71
D	1	a.m.	*S.* Typhimurium	U310	None	0.36	5.30
D	1	a.m.	*S.* Typhimurium	U310	None	<0.30	4.68
D	1	a.m.	*S.* Typhimurium	U310	None	<0.30	4.66
D	1	a.m.	*S.* Typhimurium	U302	ACSSuTTmMn	0.36	4.94
D	1	a.m.	*S.* Typhimurium	U310	None	<0.30	4.16
D	1	a.m.	*S.* Typhimurium	U310	None	<0.30	3.60
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	4.44
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	4.13
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.95
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.82
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.62
D	1	p.m.	*S.*. Derby	-	SuTTmMn	<0.30	4.02
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.99
D	1	p.m.	*S.* Typhimurium	U310	None*	<0.30	4.23
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.41
D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	3.75
D	2	a.m.	*Untypeable*	-	SSuTTmMn†	<0.30	3.59

MPN = most probable number ; T = tetracycline (30 µg), Mn = minocycline (30 µg), A = ampicillin (10 µg),
C = Chloramphenicol (30 µg), S = streptomycin (10 µg), Su = sulphonamides (300 µg), Tm = trimethoprim (5 µg).

Table 5. *Salmonella* serotypes and/or phage types, their antibiotic resistance profiles, MPN g^{-1} and *Enterobacteriaceae* (log_{10} CFU cm^{-2}) isolated from environmental swabs in the meat cutting rooms of four commercial pork abattoirs in ROI.

Site	Plant	Visit	Time	Serotype	Phage type	Antibiotic resistance	MPN cm^{-2}	*Enterobacteriaceae* log_{10} CFU cm^{-2}
Conveyor where spinal column cut	B	2	a.m.	*S.* Derby	-	TMn	0.07	1.72
	B	2	p.m.	*S.* Derby	-	TMn	0.23	1.96
Fat trimmer	B	2	p.m.	*S.* Derby	-	TMn	0.036	2.11
Table where oyster piece cut	D	1	a.m.	*S.* Typhimurium	U310	None	0.36	4.38
	D	1	p.m.	*S.* Typhimurium	U310	None	<0.30	4.08
Fat trimmer*	D	1	a.m.	*S.* Derby	-	SuTTmMn	1.10	5.33
	D	1	a.m.	*S.* Derby	-	SuTMn		
Table where spinal column cut	D	1	a.m.	*S.* Typhimurium	U302	ACSSuTTmMn	<0.30	5.24

* = Two S. Derby with different sensitivities isolated from the same sample
T = tetracycline (30 µg), Mn = minocycline (30 µg), A = ampicillin (10 µg),
C = Chloramphenicol (30 µg), S = streptomycin (10 µg), Su = sulphonamides (300 µg), Tm = trimethoprim (5 µg).

Taken from Prendergast *et al,* 2008.

NI

The prevalence (%) of *Salmonella* spp. on the pork oyster cut in the boning halls of two commercial pork abattoirs during each visit in NI is shown in Table 6. *Salmonella* was found on 44/525 (8.3%) samples. The confidence limit for this data set calculated at the 95% level was 6.01 to 10.75 %.

There was considerable variation in the mean prevalence of *Salmonella* spp. on particular sampling days ranging from 0 to 52.5% over 15 visits. On 6 of the 15 sample visits no *Salmonella* was detected. On 7 visits the prevalence ranged from 3.3 to 10% and on two visits prevalences of 15 %and 52.5% were detected.

In total, 36 isolates collected in abattoir E and were identified as *S.* Rissen (n= 21), *S.* Typhimurium (n= 8), *S.* Panama (n= 6) and S. Meleagridis (n= 1), at Abattoir F, 8 isolates were obtained and identified as *S.* Typhimurium (n= 3), *S.* Binza (n=2), *S.* Derby (n=2) and *S.* Dublin (n=1).

Table 6. Prevalence (%) of *Salmonella* spp. on pork (oyster cut) in the boning halls of two commercial pork abattoirs in NI during morning (a.m.) and afternoon (p.m.) sampling.

Abattoir	Number tested			Number positive (%)		
	a.m.	p.m.	Total	a.m.	p.m.	Total
E	15	0	15	0	0	0
E	15	15	30	0	0	0
E	20	20	40	2 (10)	2 (10)	4 (10)
E	20	20	40	2 (10)	4 (20)	6 (15)
E	20	20	40	0	2 (10)	2 (5)
E	20	20	40	0	3 (15)	3 (7.5)
E	20	20	40	0	0	0
E	20	20	40	10 (50)	11 (55)	21 (52.5)
E	20	20	40	0	0	0
E	20	20	40	0	0	0
E	20	20	40	0	0	0
F	15	15	30	0	2 (13.3)	2 (6.6)
F	15	15	30	2 (13.3)	1 (6.7)	3 (10)
F	15	15	30	1 (6.7)	1 (6.7)	2 (6.6)
F	15	15	30	0	1 (6.7)	1 (3.3)
Total	**270**	**255**	**525**	**17 (6.3)**	**27 (10.6)**	**44 (8.3)**

Conclusions

In both jurisdictions, the key finding was the enormous variation in *Salmonella* prevalence on different sampling days (0 to 31.6% in ROI and 0 to 52.5 % in NI). In both jurisdictions, the prevalence of *Salmonella* on pork cuts was significantly higher on cuts taken during afternoon production than during morning production. On particular days when *Salmonella* prevalence was high, *Enterobacteriaceae* counts were also generally high indicating breakdowns in hygiene and that monitoring of this group of microorganisms could be a useful indicator in controlling Salmonella. A better understanding of why there is such variability in the prevalence of *Salmonella* between factories and on different production days would greatly assist in reducing overall risk.

3.2 *Salmonella* status of pork cuts and products at retail

This study set out to establish the prevalence and numbers of *Salmonella* on pork cuts produced in ROI and in NI.

Sample Protocol: **ROI**

Pork samples (n = 500) were collected at random from 167 butcher shops and supermarkets located in ROI between January and November 2007. During each sampling time, at each sampling location, three pork sample types i.e., mince, pieces and chops were purchased. The methods employed for the detection and enumeration of *Salmonella* spp. and *Enterobacteriaceae* was as described earlier in Section 3.1 of this report and are fully detailed in Prendegergast *et al* 2009. In addition *Salmonella* isolates from this study and the boning hall study were sub-typed by PFGE performed according to the US PulseNet protocol (Centres for Disease Control and Prevention, Atlanta, GA, USA, 2004) with some modifications (Prendergast *et al,* 2009).

NI

Pork samples (n=200) were collected from 10 retail outlets in Belfast and Coleraine. Prepacked samples were collected from three supermarkets and loose samples from 2 butchers' shops. A total of 10 samples were collected per week over a 10 week period. Samples were cultured according to the methods described in ISO 6579 as outlined earlier in section 3.1 of this report.

Results: **ROI**

The mean prevalence (%) of *Salmonella* on pork samples taken in butcher shops and supermarkets in ROI was 13/500 (2.6%). The number of *Salmonella* positive samples by pork type and by outlet is shown in Table 7. The numbers and characteristics of the *Salmonella* isolates and the corresponding *Enterobacteriaceae* counts are shown in Table 8. The presence of *Salmonella* on pork samples was associated with higher *Enterobacteriaceae* counts ($P<0.01$) indicating the role of good hygiene in controlling *Salmonella*. Genetic fingerprinting using PFGE showed that three *S*. Typhimurium DT193 isolates recovered on the same sampling date from the same butcher shop (B), but from three different pork sample types i.e. minced, pieces and a chop were genetically indistinguishable, indicating that cross contamination had occurred in the shop. On a different sampling date, four isolates of *S*. Typhimiurium DT193 were recovered from supermarket D (positive pork pieces and chop) and Supermarket E (positive pork pieces and a chop) which was located approximately 26 km from supermarket D). Interestingly these two supermarkets belong to the same chain and all pork samples were supplied over the counter (i.e. not packaged). This indicates contamination at the supplier stage and demonstrates how a pathogen can be spread easily across a wide area and consumer base from a single supplier.

Table 7. Number of *Salmonella* positive samples classified by pork type, outlet and by outlet within pork types in ROI (Prendergast *et al*, 2009).

Factor	Pork type, outlet and region	No. samples taken	No. *Salmonella* positive (%)
Pork type - chop	Butcher	90	1 (1.11)
	Supermarket	197	6 (3.05)
Pork type - mince	Butcher	53	2 (3.77)
	Supermarket	32	0 (0)
Pork type - pieces	Butcher	80	1 (1.20)
	Supermarket	48	3 (6.67)
Total		500	13 (2.6)

Table 8. Pork samples positive for *Salmonella* spp. along with *Enterobacteriaceae* counts from butcher shops and supermarkets in ROI isolated in 2007 (Prendergast *et al*, 2009).

Date Isolated	Pork type	Supermarket/ butcher	Serotype	*Salmonella*		MPN g^{-1}	*Enterobacteriaceae* (log_{10} CFU g^{-1})
29/01	Mince	Butcher A	Rissen	NA†	T	0.30	5.20
29/01	Mince	Butcher B	Typhimurium	DT193	CSSuTTm	0.92	4.15
29/01	Pieces	Butcher B	Typhimurium	DT193	CSSuTTm	1.10	3.58
29/01	Chop	Butcher B	Typhimurium	DT193	CSSuTTm	0.36	3.14
28/03	Pieces	Supermarket A	Typhimurium	DT120	ACSSuT	<0.30	2.83
20/04	Chop	Supermarket B	Derby	NA	SSuT	<0.30	3.70
20/04	Chop	Supermarket C	Typhimurium	U310	STTm	<0.30	3.03
23/07	Pieces	Supermarket D	Typhimurium	DT193	ACSSuTTmK	2.10	5.21
23/07	Chop	Supermarket D	Typhimurium	DT193	ACSSuTTmK	1.50	5.25
23/07	Pieces	Supermarket E	Typhimurium	DT193	ACSSuTTmK	<0.30	4.39
23/07	Chop	Supermarket E	Typhimurium	DT193	ACSSuTTmK	0.92	4.41
06/09	Chop	Supermarket F	Typhimurium	DT104b	ACSSuT	<0.30	5.05
06/09	Chop	Supermarket G	Typhimurium	DT104	ACSSuT	<0.30	2.64

*A = ampicillin (10 µg); C = chlorampenicol (30 µg); K = kanamycin (30 µg); S = streptomycin (10 µg); Su = sulphonamides (300 µg); T = tetracycline (30 µg) and Tm = trimethoprim (5 µg)
†NA = Not Applicable

Results: NI

The overall *Salmonella* prevalence was 5.5%, with a prevalence of 8% in samples taken from Belfast and 3% in Coleraine. The rate of isolation was highly variable over each sampling week, with only 4 of 10 sampling weeks resulting in positive samples, with most positives detected on just two sample weeks (7 and 8) (Figure 2).

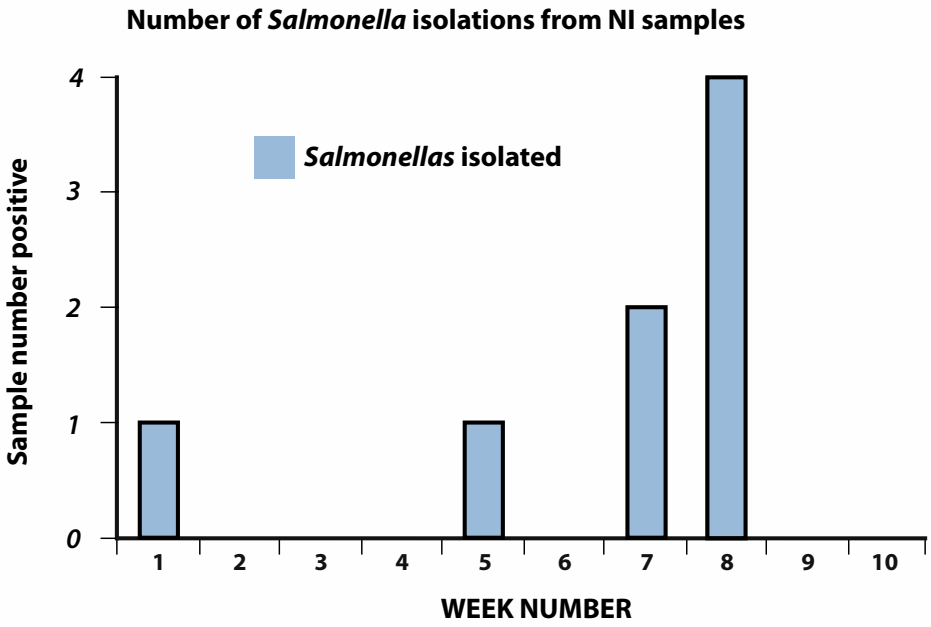

Figure 2: *Salmonella* isolation from different sample weeks, Belfast samples only

Conclusion

In both jurisdictions the key finding again was the enormous variation in *Salmonella* prevalence on different sampling days. There was also evidence of cross contamination of *Salmonella* between different samples purchased from the same shop. The prevalence of *Salmonella* on pork cuts was also associated with higher *Enterobacteriaceae* counts highlighting the impact of hygiene in pathogen control at retail level. A better understanding of why there is such variability in the prevalence of *Salmonella* between sample days would greatly assist in reducing overall risk.

3.3 Tracking of *Salmonella* on pig through the slaughter process

ROI: *Sample plan and analysis*

Between November 2005 and March 2007 pig herds defined by serology as Category 1 (< 10%) (n=4), Category 2 (10 ≥ and ≤ 50%) (n=4) and Category 3 (> 50%) (n=5) were selected for tracking. Between 10 and 21 pigs from the each of thirteen different herds were tracked from farms through three large scale commercial pork abattoirs denoted as A, B and C, and one small scale commercial pork abattoir denoted as D. Herds 11, 12 and 13, abattoir

D, were tracked from the slaughter stage only. The pens of the finishing pigs were sampled a week prior to scheduled slaughter to estimate the *Salmonella* status of the individual pens with the assumption that a positive pen contained at least one pig shedding *Salmonella* serotypes. From Category 2 and 3 herds, pigs were randomly selected from the pen with the greatest number of positive swab samples while on Category 1 farms pigs were randomly selected from pens which tested negative for *Salmonella* spp. Each pig to be tracked was slap marked prior to departure with a unique identifying number and sampled at the stages outlined in Figure 3.

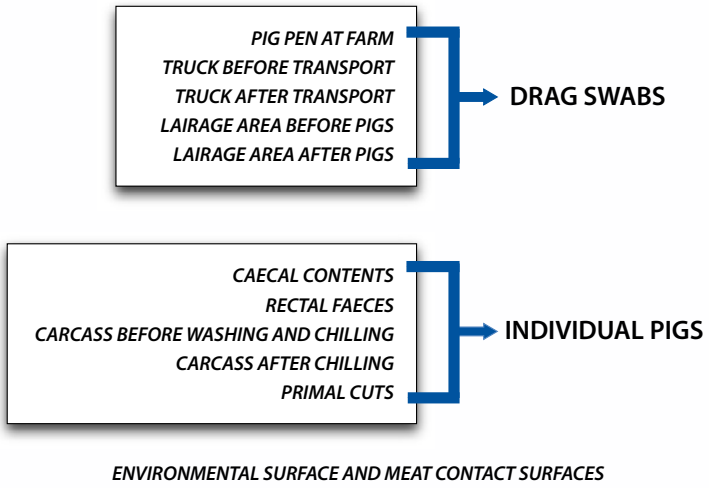

Figure 3. Sites tested for *Salmonella* in tracking study

The trucks that transported the groups of pigs studied were commercial pig transporters used by the individual farms and only transported pigs originating from a single herd on any particular journey. Trucks were swabbed prior to loading of pigs on the farms, following unloading at the abattoir and after washing. Pigs were unloaded into lairage pens immediately upon arrival at the abattoir. At each of these stages 5 to 10 sponge swabs were taken each covering a total surface area of about 1 m_2.

From each tracked pig, gastrointestinal tracts were removed from the line and placed in clean plastic trays (one per tract) before sample collection. For each pig, the caecum (50 ml) and rectum (20 g) were taken.

The carcass was swabbed in accordance with the four EU sampling sites outlined in EU directive 471/2001/EU, namely ham, back, belly and jowl. After swabbing the carcasses continued into the chill and were stored under normal process conditions alternate sides of the carcass were swabbed pre and post chill.

In the boning hall each carcass was split into four primal cuts. One leg from each carcass was tracked and approximately 50g pork was aseptically excised. Pork cut samples were collected from the boning hall for herds 1 to 10 only.

Swabs of the abattoir environments (100 cm_2) area were taken using polyurethane sponges at various locations on the slaughter line in each of the four slaughter plants and from meat contact surfaces in the boning

hall in slaughter plants A, B and C. The hands of personnel involved in various carcass dressing operations were also swabbed. All samples were screened for the presence and numbers of *Salmonella* spp using a real time PCR method developed by Prendergast *et al,* 2008 as outlined earlier in Section 3.1. Carcass swabs, environmental swabs and pork primal cut samples were also examined for the numbers of *Enterobacteriaceae* numbers using the method described in the British Standards BS 5763 part 10 1993.

All isolates confirmed as *Salmonella* spp. underwent characterisation by PFGE (adapted pulse net protocol). PFGE profiles were subjected to computer assisted DNA fingerprint analysis using BioNumerics software with a cut off at > 80% similarity.

NI: *Sample plan and analysis*

A smaller tracking study was conducted in NI. In this study 120 pigs were tracked through a single high-throughput abattoir. Animals were sampled in batches of 10. Faeces were collected to determine carrier status and the carcass was swabbed (pre-and post-chilling) using the procedures previously applied throughout this study. Sample analysis was as described above in Section 3.1.

Results: **ROI**

The results showed that transport of pigs in contaminated trucks has the potential to allow negative pigs to be infected. After the trucks were washed they were visibly clean and thus the contamination levels were reduced i.e. the surfaces were no longer covered in dung. However, the salmonellae were sometimes dispersed more widely around the truck and therefore the prevalence (number of swabs positive) was sometimes greater after washing compared to before. Figure 4 summarises the prevalence of *Salmonella* in trucks before and after the pigs were loaded, and after they were washed. Cold power washing of trucks was inadequate especially those used to transport Category 3 herds which in some cases were significantly more contaminated after washing.

Figure 5 summaries the prevalence of *Salmonella* in the lairage area before and after pigs arrived. The lairage areas were very contaminated with *Salmonella* spp. posing a risk for incoming negative pigs. In Category 3 herds, *Salmonella* was present in the intestinal contents of 52% of pigs and genetic fingerprinting (sub-typing) of these isolates indicated 95% of these isolates were tracked back to farm or picked up during transport. In Category 1 herds, *Salmonella* was present in 23 of pigs and 71% of these *Salmonella* were tracked back to lairage when tracking was possible. Figure 6 shows the results for *Salmonella* prevalence in caecal and rectal contents from each of the herds.

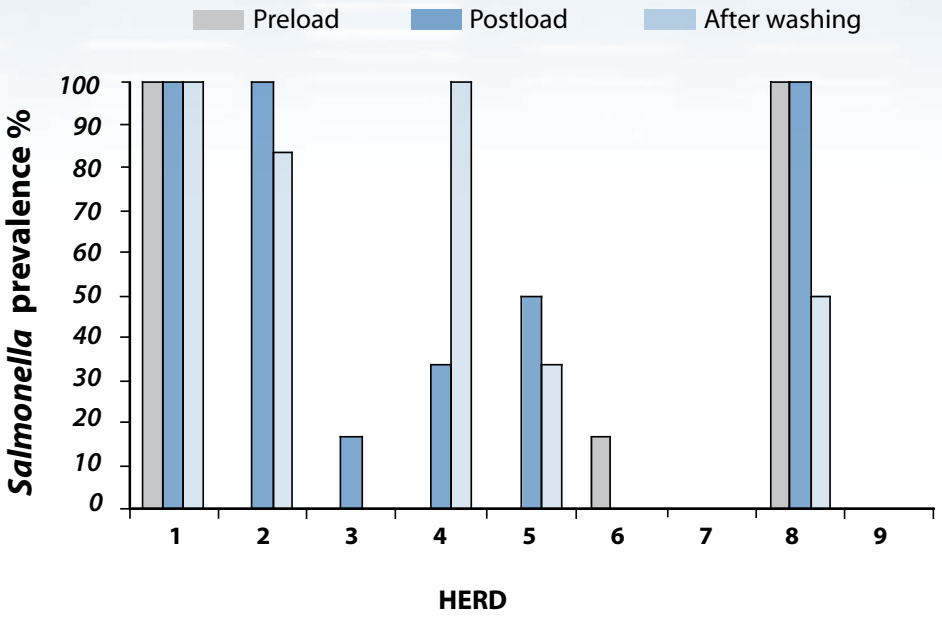

Figure 4: Percentage of *Salmonella* positive samples collected from trucks (ROI) before pigs and after pigs were loaded and after they were washed.

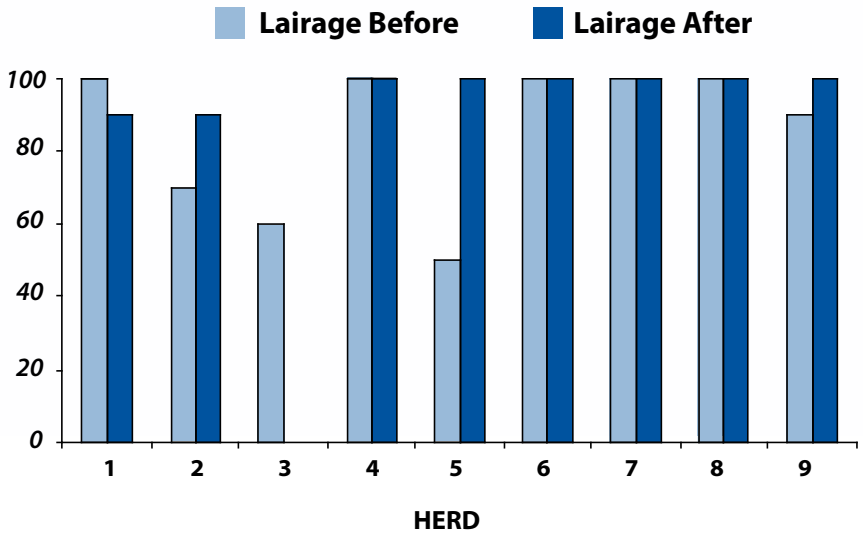

Figure 5: Percentage of *Salmonella* positive samples collected from lairage pens (ROI) before and after pigs arrived.

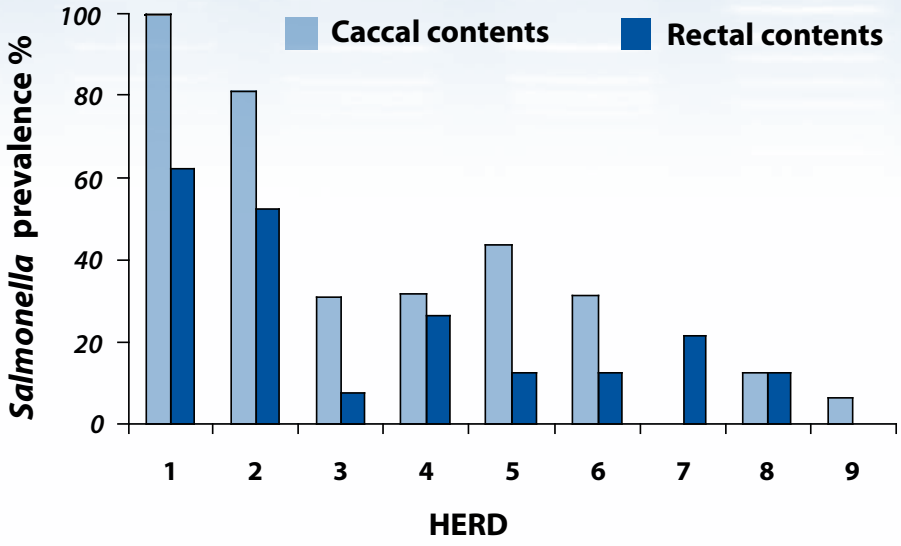

Figure 6: Percentage of *Salmonella* positive caecal and rectal contents in pig herds (ROI).

Table 9 summarises the historical serological rolling average for the herd, the number of animals tracked from each herd, and the stages and number of animals which were positive for *Salmonella* in each group of tracked animals. Of the 193 pigs tracked in the study, 16 %, 72% and 45% of Category 1, 2 and 3 herds respectively were positive for caecal carriage of *Salmonella.* At the post-chill stage, 0, 2 and 7 % of carcass from Category 1, 2 and 3 herds, respectively, were positive for *Salmonella.* Overall, for herd Categories 1 and 2 there was no significant association between *Salmonella* infection of the pig and the *Salmonella* status of its carcass. However, there was a significant correlation ($P < 0.05$) between rectal carriage and pre-chill carcass contamination of pigs originating from Category 3 herds. Overall, when all herd categories were analysed together at individual pig level, no association between internal contamination or infection (caecal, rectal carriage) with external contamination (pre chill, post chill, pork cut) was found.

Once a pig has entered the slaughter process, the final *Salmonella* contamination of the dressed carcass was shown by genetic fingerprinting, to originate from at least one of the following sources: the pig itself, previously slaughtered pigs via the processing machinery or personnel. The final contamination level of the carcass will depend on the combined impact of these probabilities during the day. The hands of an operative employed in evisceration and debunging were positive for *Salmonella* on two sampling periods in two different plants and equipment was also implicated in contamination at two plants.

Tables 10 and 11 overview the tracking of *Salmonella* on individually tracked pigs from category 1 and 3 herds respectively. This demonstrates the routes and sources of contamination, with genetic fingerprinting (PFGE) used to confirm that the *Salmonella* tracked were identical. *Salmonella* isolates from the lairage, caecal content, rectal faeces and carcasses of pigs from two of three Category 1 herds were indistinguishable (Herds 7 and 8, Table 10), suggesting that the source of contamination of pigs and carcasses originated in the lairage

environment. All Category 3 herds (n = 5) tracked through the slaughter process resulted in contaminated carcasses (n = 30) and in contaminated pork cut product (n = 2) on one sampling occasion. Isolates from post pig lairage samples, caecal content and rectal faeces were genetically related to carcass samples (n = 15) for pigs within the same herd on three sampling occasions. In addition, molecular typing linked carcass samples (n = 2) to the rectal faeces on another occasion when lairage samples were not collected. Positive carcasses from Category 3 pigs (1/30) were only linked to the pre pig lairage environment on one occasion (Herd 4, PFGE profile P0002). This suggests the pig's own intestinal content as the likely source of contamination.

There was also a strong association (P< 0.01) between *Enterobacteriaceae* counts and *Salmonella* status of pre chill carcass swabs, however no association was observed for post-chill carcass swabs . It can therefore be hypothesised that chilling may have an effect on *Salmonella* recovery. A significant association (P<0.05) was found between *Enterobacteriaceae* counts and the *Salmonella* status of pork cut samples. Cross contamination in the boning hall may therefore have played a role.

Table 9: Overview of the Category and number of pigs tracked from each herd through the four slaughter plants in ROI. Results are shown for each sample type that tested positive for the presence of *Salmonella* sp. at the key stages investigated.

Category and rolling average (%)	1 (6.7)	1 (7.3)	1 (0)	1 (6.7)	Total Cat 1(%)	2 (49)	2 (21)	2 (44)	2 (36)	Total Cat 2(%)	3 (62)	3 (95)	3 (83)	3 (59)	3 (51)	Total Cat 3(%)
Abbatoir	C	A	B	D		A	A	A	D		B	C	B	B	D	
Herd	7	8	9	12		1	2	3	13		4	5	6	10	11	
No. Animals sampled	14	16	16	10	56	16	21	13	10	60	19	16	16	16	10	77
No. pos caecal	0	2	1	6	9 (16)	16	17	4	6	43 (72)	6	17	5	16	1	35 (45)
No. pos rectal	3	2	0	2	7 (12)	10	11	1	4	26 (43)	5	2	2	16	1	26 (34)
No. pos pre-chill	1	1	0	1	3 (5)	0	0	0	0	0 (0)	7	2	11	5	1	26 (34)
No. pos. post-chill	0	0	0	0	0 (0)	1	0	0	0	1 (2)	0	1	NS	2	1	4 (7)
No. pos pork cuts	0	0	0	NS	0 (0)	0	0	0	NS	0 (0)	0	2	NS	0	NS	2 (4)

Note: the rolling average is the result of a national programme which serologically tests 24 pigs from each herd three times per year.

NS = Not Sampled

Table 10: The number of *Salmonella* serotypes / phage types recovered from each sampling stage for category 1 herds. Where the sample was isolated from a pig the pig ID number is stated. The pulse field profile number for isolates ≥ 80% similar is also listed.

Plant	Herd	Sample [Positive Samples / Tested (n)]	Serovars and Phage Types (n)	Pig ID number	PFGE profile [Serotype (number related/isolated, profile ID number)]
C	7	L_1 (10/10)	DT208 (7), DT193 (1), PTU311 (1), Bredeney (1)	-	T (6/8, P0008)
		L_2 (10/10)	DT208 (10)	-	T (9/10, P0008)
		Environmental (3/6)	Unnamed (2)[a,b], DT208 (1)[c]	-	T (3/3, P0008)
		Caecal (0/14)	All Negative	-	-
		Rectal (3/14)	DT208 (3)	4, 5, 6	T (3/3, P0008)
		Carcass Pre-Chill (1/14)	DT208 (1)	17	T (1/1, P0008)
		Carcass Post-Chill (0/8)	All Negative	-	-
		Pork Cut (0/8)	All Negative	-	-
A	8	L_1 (5/5)	DT104b (5)	-	T (5/5, P0010)
		L_2 (5/5)	Kimuenza (4), Infantis (1)	-	K (4/4, P0009)
		Environmental (1/12)	DT104b (1)[d]	-	T (1/1, P0010)
		Caecal (2/16)	Kimuenza (2)	8, 17	K (2/2, P0009)
		Rectal (2/16)	DT104b (2)	1, 15	T (2/2, P0010)
		Carcass Pre-Chill (1/16)	DT104b (1)	3	T (1/1, P0010)
		Carcass Post-Chill (0/16)	All Negative	-	-
		Pork Cut (0/16)	All Negative	-	-
B	9	L_1 (9/9)	DT143 (4), DT104 (2), Manhattan (2), DT193 (1)	-	-
		L_2 (10/10)	DT143 (9), DT193 (1)	-	-
		Environmental (0/9)	All Negative	-	-
		Caecal (1/16)	DT104 (1)	1	-
		Rectal (0/16)	All Negative	-	-
		Carcass Pre-Chill (0/16)	All Negative	-	-
		Carcass Post-Chill (0/16)	All Negative	-	-
		Pork Cut (0/16)	All Negative	-	-
D	12	L_1 (0/0)	Not Sampled	-	-
		L_2 (0/0)	Not Sampled	-	-
		Environmental (0/2)	All Negative	-	-
		Caecal (6/10)	Unnamed (6)	1 - 4, 7, 9	-
		Rectal (2/10)	Unnamed (2)	3, 4	-
		Carcass Pre-Chill (1/10)	DT104b (1)	2	-
		Carcass Post-Chill (0/10)	All Negative	-	-
		Pork Cut (0/0)	Not Sampled	-	-

Key: Where S. Typhimurium was isolated the phage type is displayed.
L_1, lairage before pigs; L_2, lairage after pigs; a Conveyor primal stage; b Conveyor leg drop; c Conveyor after leg drop; d Hands debung operative.
– = Not Applicable. T = *S.* Typhimurium; K = *S.* Kimeunza.

Table 11: The number of *Salmonella* serotypes / phage types recovered from each sampling stage for category 3 herds. Where the sample was isolated from a pig the pig ID number is stated.

Plant	Herd	Sample [Positive Samples / Tested (n)]	Serovars and Phage Types (n)	Pig ID number	PFGE profile [Serotype (number related/isolated, profile ID number)]
B	4	L_1 (10/10)	Manhattan (7), Reading (1), Anatum (1), Derby (1)	-	D (1/1, P0002); M (5/7, P0003)
		L_2 (10/10)	DT193 (9), Derby (1)	-	T (9/9, P0004)
		Environmental (0/9)	All Negative	-	-
		Caecal (6/19)	DT193 (6)	5, 8, 9, 16, 17, 23	T (6/6, P0004)
		Rectal (5/19)	[g]DT193 (4), [h]Manhattan (1)	[g](3, 5, 8, 9); [h](19)	T (4/4, P0004); M (1/1, P0003)
		Carcass Pre-Chill (7/19)	[g]DT193 (5), [i]Anatum (1), [j]Derby (1)	[g](3, 9, 17, 19, 23); [i](1), [j](5)	D (1/1, P0002); T (4/5, P0004)
		Carcass Post-Chill (0/16)	All Negative	-	-
		Pork Cut (0/15)	All Negative	-	-
C	5	L_1 (5/10)	Panama (2), DT104 (2), PTU288 (1)	-	T (3/3, P0005)
		L_2 (10/10)	DT104b (8), Manhattan (2)	-	T (7/8, P0005); T (1/8, P0006)
		Environmental (0/9)	All Negative	-	-
		Caecal (7/16)	DT104b (7)	2 -4, 8, 13, 15 -16	T (7/7, P0005)
		Rectal (2/16)	DT104b (2)	3, 18	T (2/2, P0005)
		Carcass Pre-Chill (2/15)	DT104b (2)	3, 17	T (2/2, P0006)
		Carcass Post-Chill (1/15)	DT104b (1)	14	T (1/1 P0006)
		Pork Cut (2/15)	DT104b (2)	3, 12	T (2/2, P0005)
B	6	L_1 (10/10)	Derby (5), Derby (2), London (2), Manhattan (1)	-	-
		L_2 (10/10)	Bredeney (3), London (2), PTU302 (2),		
			Reading (1), Anatum (1), Manhattan (1)	-	T (1/2, P0007)
		Environmental (0/9)	Not Sampled	-	-
		Caecal (5/16)	[k]PTU302 (4), [l]DT193 (1)	[k](5, 15 - 16, 20); [l](8)	T (4/5, P0007)
		Rectal (2/16)	PTU302 (2)	20, 21	T (2/2, P0007)
		Carcass Pre-Chill (11/16)	[k]PTU302 (10), [m]Manhattan (1)	[k](4, 7, 13, 15, 17, 19, 20, 21, 24, 25); [m](9)	T (10/10, P0007)
		Carcass Post-Chill (0/16)	Not Sampled	-	-
		Pork Cut (0/15)	Not Sampled	-	-
B	10	L_1 (5/8)	Agona (2), Derby (1), DT193 (1), Rough (1)	-	-
		L_2 (8/8)	Reading (8)	-	R (7/8, P0011)
		Environmental (2/9)	[d]Derby (1), [b]Typhimurium (1)	-	D (1/1, P0012)
		Caecal (16/16)	Reading (16)	-	R (1/16, P0011)
		Rectal (16/16)	Reading (16)	-	R (4/16, P0011)
		Carcass Pre-Chill (5/15)	[n]Derby (4), [o]Reading (1)	[n](3, 7, 8, 15); [o](2)	D (4/4, P0012); R (1/1, P0011)
		Carcass Post-Chill (2/15)	[n]Derby (1), [p]Manhattan (1)	[n](4); [p](7)	D (1/1, P0012)
		Pork Cut (0/15)	All Negative	-	-
					continued over

Table 11: *continued*

Plant	Herd	Sample [Positive Samples / Tested (n)]	Serovars and Phage Types (n)	Pig ID number	PFGE profile [Serotype (number related/isolated, profile ID number)]
D	11	L_1 (0/0)	Not Sampled	-	-
		L_2 (0/0)	Not Sampled	-	-
		Environmental (0/3)	All Negative	-	-
		Caecal (1/10)	Typhimurium (1)	5	-
		Rectal (1/10)	Derby (1)	2	D (1/1, P0013)
		Carcass Pre-Chill (1/10)	Derby (1)	2	D (1/1, P0013)
		Carcass Post-Chill (1/10)	Unnamed (1)	4	D (1/1, P0013)
		Pork Cut (0/0)	Not Sampled	-	-

Key: Where S. Typhimurium was isolated the phage type is displayed.
L_1, lairage before pigs; L_2, lairage after pigs, b Conveyor leg drop; d Hands debung operative.
g – p the serotype or phage type was isolated from the pig ID number indicated.
– = Not Applicable; D = *S.* Derby; M = *S.* Manhattan; T = *S.* Typhimurium; R = *S.* Reading.

Results: Northern Ireland

Overall 10 pigs that had originates from herds in NI and 12 from herds ROI yielded at least one positive sample during the sampling procedures (Figure 7).

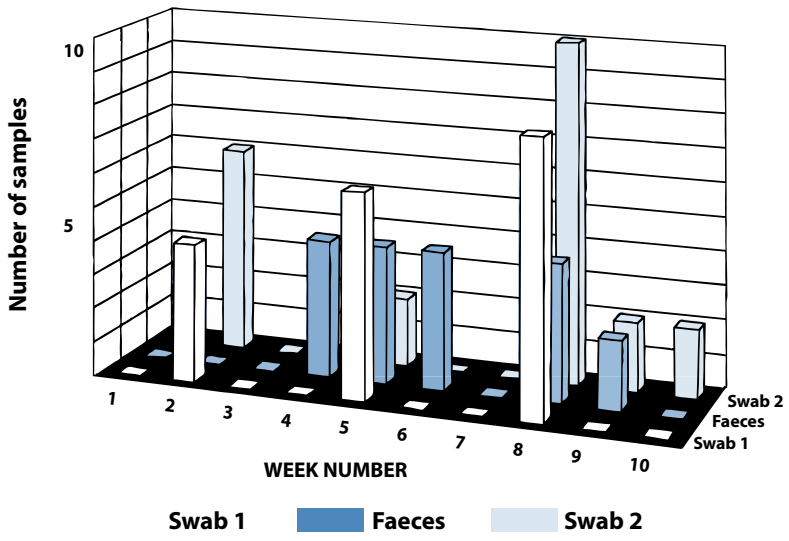

Figure 7. *Salmonella* isolations during tracking study in NI (12 carcasses per week for 10 weeks).

The faecal carriage rate for *Salmonella* was 7.5% on carcasses pre wash and pre chill the prevalence was 7.5% while the prevalence increased to 9.2% on carcass post chill. The *Salmonella* serotypes recovered included *S.* Typhimurium, *S.* Derby and *S.* Rissen (Table 12) and the antibiotic resistant profiles are shown in Table 13.

Antibiotic resistance profiles have been established for 55 out of 68 of the *Salmonella* isolates recovered from pigs (Table 13).

Table 12. *Salmonellas* serotypes found during tracking investigation of pigs (n=120) at an NI abattoir.

Pig number	Pig Origin	Day 1		Day 2
		Carcass swab	Faecal sample	Carcass swab
16	NI	*S.* Typhimurium		*S.* Typhimurium
17	NI	*S.* unnamed		*S.* unnamed
18	NI			*S.* unnamed
45	ROI		*S.* Typhimurium	
46	ROI		*S.* Typhimurium	
50	ROI		*S.* Typhimurium	*S.* Typhimurium
54	ROI		*S.* Typhimurium	
57	ROI	*S.* Typhimurium		
58	ROI	*S.* Typhimurium		
60	ROI	*S.* Typhimurium		
70	NI		*S.* Rissen	
71	NI		*S.* Rissen	
85	ROI		*S.* Rissen	
88	NI	*S.* Derby		*S.* Derby
89	NI	*S.* Derby		*S.* Derby
90	NI	*S.* Derby		*S.* Derby
91	ROI			*S.* Derby
92	ROI	*S.* Derby	*S.* Rissen	
96	ROI			*S.* Rissen
107	NI			*S.* Typhimurium
108	NI		*S.* Typhimurium	
110	ROI			*S.* Typhimurium

Table13 . Antibiotic resistance profile of strains isolated from pig meat in NI

Salmonella serotype	Antibiotic Profile	No. of Isolates
Typhimurium	ACSSuT SXT	2
Typhimurium	SSuT SXT	7
Typhimurium	T	1
Rissen	T	16
Rissen	AST APR	2
Rissen	Su	1
Panama	Sensitive	6
Derby	Sensitive	1
Meleagridis	Sensitive	1
Binza	Sensitive	1

Conclusion

The study highlighted that at any individual pig level there was little correlation between the *Salmonella* serological status and bacteriological status of caecal and rectal contents when animal presented for slaughter. Nonetheless the majority of positive carcass originated from category 3 herds.

This study found that the lairage was a source of *Salmonella* contamination for pigs and carcasses from Category 1 herds, and that pigs from Category 3 herds significantly contaminated the lairage environment. Separating pigs from low and high risk herds in the lairage environment and disinfecting the pens on a daily basis could potentially reduce the number of contaminated carcasses. The lairage and the pigs' own intestinal content were found to be a source of *Salmonella* for pigs from low and high herd prevalence respectively

The study showed that contamination could be transmitted from one contaminated carcass or meat cut to another and that equipment and surfaces play a very important role in cross contamination. There was high variability in cross contamination from day to day and abattoir to abattoir. This study has shown that the lairage was a major source of cross contamination with *Salmonella* as were the hands of evisceration operatives employed in debunging and conveyor belts and equipment in the boning hall. Cross contamination within the slaughter plant environment can account for up to 69% of contamination on carcasses and pork cuts. There was a strong association found between Enterobacteriaecea counts (hygiene indicators) and *Salmonella* status on pre chill carcass swab and also a significant association between Enterobacteriaecea counts and the *Salmonella* status of pork cut samples.

4. Quantitative risk assessment model

The risk model was initially developed using ROI data and then run using NI data.

Risk assessment model (ROI)

The model is described in full in Gonzales-Baron *et al* (2008a, 2008b, 2009a and 2009b)

Model Inputs

The main input parameter of this model was the *Salmonella* prevalence in pigs' caecal contents in ROI. The microbiological results from the current study (Section 3) and two previous studies were used (Table 14). An uncertainty distribution about the prevalence of *Salmonella* in the caecal contents of ROI slaughter pigs was modelled using a beta distribution.

Table 14. Data sources utilized for the approximation of the prevalence of *Salmonella* in caecal contents of slaughter pigs in ROI.

Study	Source	Total number of caecal samples of slaughter pigs taken in Ireland	Salmonella-positive caecal samples (with account taken of test sensitivity)
1	Duggan *et al.* (2009)	193	107
2	Quirke *et al.* (2001)	419	133
3	UCD study (2000)*	471	99
	Pooled data	1083	339

(*) Unpublished results from a survey study on the incidence of *Salmonella* in ROI slaughterhouses conducted in University College Dublin.

Estimation of prevalence of Salmonella on eviscerated pigs

In order to establish the relationship between the proportion of slaughter pigs carrying *Salmonella* in their caeca entering the slaughter lines and the proportion of *Salmonella*-positive carcasses at the point of evisceration in the same slaughter batches, a stochastic regression analysis was performed. Data describing this relationship were found in seven individual studies (Table 15). Differences in test sensitivities between studies were factored into the predicted prevalence's. Equally, as slaughter procedures may not necessarily be uniform across these studies, a weighted linear regression analysis was considered suitable.

Contamination factor for splitting and trimming

Cross contamination of *Salmonella* from the splitting machine to the carcass may occur. Hald *et al.* (2003), Botteldoorn *et al.* (2003) and Swanenburg *et al.* (2001) reported *Salmonella* contamination on splitting machines in 10 to 33% of the sampling visits to abattoirs. Assuming that the average cross contamination of *Salmonella*

during splitting and trimming in Irish abattoirs was comparable to the one simulated for Danish abattoirs (increase of 16% in Alban and Stark (2005)), and that the findings of Davies *et al.* (1999) represented the worst-case scenario (where splitting increased *Salmonella* prevalence in 50%), the *Salmonella* prevalence on carcasses after splitting and trimming was calculated.

Table 15: Data Sources for Regression Analysis to estimate *Salmonella* Prevalence on Eviscerated Carcasses

Source	Proportion of *Salmonella* positive caecal samples (x')	Proportion of *Salmonella* positive eviscerated carcasses (y')
Duggan *et al.* (2009)*	99/193	29/191
Sorensen *et al.* (2004)	480/1658	161/1665
Kranker *et al.* (2003)	31/122	11/117
Quirke *et al.* (2001)	133/419	43/419
Davies *et al.* (1999)	287/2205	157/2211
Morgan *et al.* (1987)	100/149	42/150
Morgan *et al.* (1987)	49/145	19/148
Morgan *et al.* (1987)	39/151	14/150
Oosterom *et al.* (1985)	55/210	27/210

(*) Article under preparation

Reduction factor for final rinsing

It was assumed that the average level of *Salmonella* decontamination for final washing achieved in a common ROI abattoir was similar to that reported in a UK study (Davies *et al.,* 1999) which combined the results from two abattoirs. There were 15/75, samples positive for *Salmonella* before final rinsing and 9/79 positive samples at the entrance to the chill. A reduction factor for final washing could thus be modelled from these data. The prevalence of *Salmonella* on pig carcasses after washing was, therefore, the multiplication of the reduction factor for washing by the prevalence of *Salmonella* on pig carcasses after splitting and trimming.

Reduction factor for chilling

The impact of chilling on the recovery of *Salmonella* from pork carcasses has been studied by a number of groups. Data on *Salmonella* prevalence on pig carcasses before chilling and after chilling (~5°C, 18-24 h) were taken from seven published studies (Lima *et al.* 2004; Botteldoorn *et al.* 2003; Bouvet *et al.* 2003; Quirke *et al.* 2001; Davies *et al.* 1999; Saide-Albornoz *et al.* 1995; Oosterom *et al.* 1985), and the tracking study form the current project (Section 3) and a UCD study (1999-2000). A meta-analysis technique was used to describe the impact of chilling and is described in detail by Gonzales Barron *et al.* (2008b).

Contamination factor in boning halls

Berends *et al.* (1998) estimated that the contribution of inadequate cleaning and disinfection on any given day is about 9-13% with respect to all contamination that occurs during a full working day. In other words, when *Salmonella*-positive carcasses are being processed, up to ~90% of all cross contamination during cutting is unavoidable, and the remaining ~10% results from *Salmonella*-positive carcasses being processed earlier that day while cleaning and disinfection had been inadequate. In a survey of *Salmonella* contamination in boning halls (carried out in four ROI abattoirs), *Salmonella* on conveyor belts was detected in 2 out of 9 visits (22%). Thus, assuming that cleaning and disinfection is carried out 2-4 times a day (Berends *et al.* 1998), it is estimated that the cleaning and disinfection process is carried out incorrectly at least once a day. The contribution of inadequate cleaning and disinfection (9-13%) to the final prevalence and the increase in *Salmonella* prevalence during jointing was factored into the model.

Model Output

The model was developed in Microsoft Excel using the @Risk add-in (Industrial Edition version 4.5.2, Palisade, NY), and run for 10,000 iterations using Latin Hypercube sampling.

The *Salmonella* prevalence in caecal contents of slaughter pigs was estimated at 0.313 (95% CI: 0.286 – 0.341; Figure 8, and Table 16).

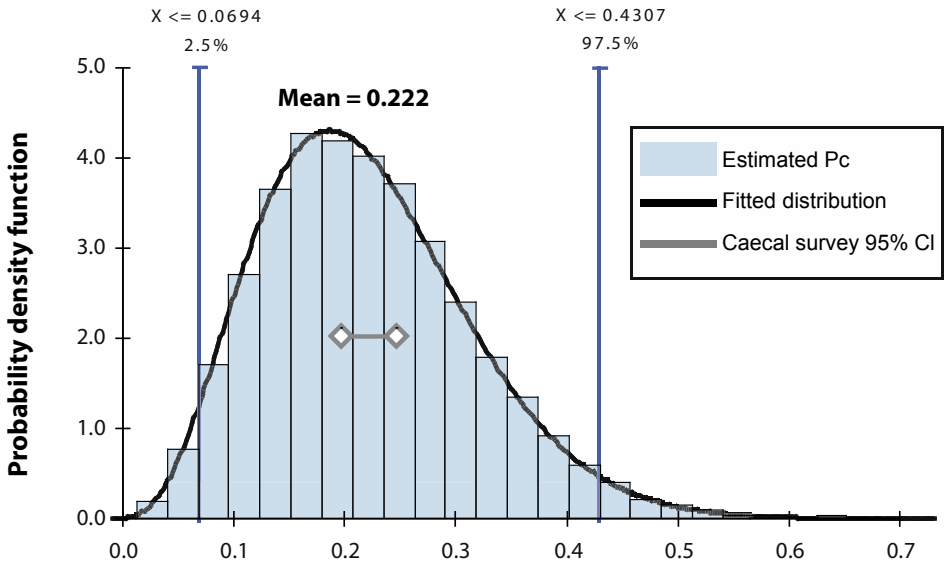

Figure 8: Predicted prevalence of *Salmonella* in pig caecal contents

Table 16: Mean, Standard Deviation and Confidence Intervals (95% CI) for the Model's Prevalence Values

Prevalence	Mean (Standard deviation)	95% CI
Caecal (Pc)	0.313 (0.0140)	[0.286 0.341]
After evisceration (Pev)	0.119 (0.0694)	[0.007 0.268]
After splitting (Psp)	0.142 (0.0836)	[0.009 0.324]
After final rinsing (Pfr)	0.088 (0.0645)	[0.005 0.246]
After chilling (Pch)	0.038 (0.0285)	[0.002 0.110]
After jointing (Pj)	0.039 (0.0300)	[0.003 0.115]

In general, at individual pig level at the slaughterhouse, *Salmonella* caecal prevalence of pigs in Europe has been reported to vary widely (3-40%) (Table 15). The relatively high prevalence of *Salmonella* present in the caeca of slaughter pigs in ROI appears to be common in other countries such as UK and France. Whereas in a UK national survey of 34 pig abattoirs in England, Scotland and Wales (Davies *et al.* 2004), 23% (578/2509) of the caecal samples were *Salmonella* positive; Beloeil *et al.* (2004), sampling from 18 French slaughterhouses, found that 24.8% (256/1030) of caecal samples tested positive for Salmonella. Some of these differences may be related to the presence and severity of the application of national programmes for *Salmonella* control at farm level. These programmes appear to be effective, producing much lower incidences of *Salmonella* in finished pigs being dispatched for slaughter.

Figure 9 illustrates the role of uncertainty for the estimation of *Salmonella* prevalence on eviscerated pig carcasses.

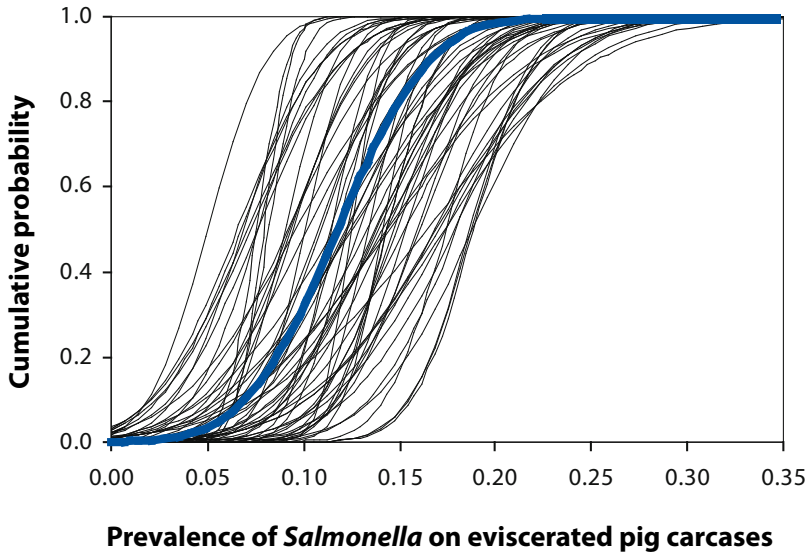

Figure 9: Cumulative Probability Distribution for Prevalence of *Salmonella* on pig carcasses after Evisceration.

The model output of *Salmonella* prevalence on pig carcasses after evisceration (11.9%) was numerically close to the results of Pearce *et al.* (2004) who recovered 10% (2/20) positive swabs after evisceration from an ROI slaughterhouse. The prevalence of *Salmonella* on pig carcasses after splitting and trimming was estimated to be on average 14.2%. A comparable proportion of positive swabs after splitting and trimming was recovered from a large abattoir in the UK (14% (7/50); Davies *et al.* 1999), while a higher proportion of 16.7% (5/30) of carcasses tested positive for *Salmonella* after splitting in a large abattoir in Brazil (Lima *et al.* 2004).

At the end of the slaughter line, before chilling, the *Salmonella* prevalence on carcasses of ROI abattoirs was estimated to be on average ~8.8%. This is lower than that recovered in the microbiological study in this project (Section 3) at ~16 %.

The model estimated *Salmonella* at a prevalence of 3.8% on chilled pig carcasses (Table 18). Bouvet *et al.* (2003) who sampled carcasses after chilling from three French slaughterhouses, found that 3.3% (6/182) of the carcass swabs were *Salmonella* positive. Within the 95% CI estimated from this simulation (1-9%), also lie the prevalence of 5.7% (12/210) found by Oosterom *et al.* (1985) and the prevalence of 1.4% (3/213) found by Swanenburg *et al.* (2001), both from Dutch slaughterhouses.

The cross contamination factor for jointing increased the *Salmonella* prevalence to 3.9% (95% CI: 0.3-11.5%). The shape of the output distribution for the prevalence of *Salmonella* in pork joints produced in Irish boning halls is shown in Figure 13 ('Regressional model').

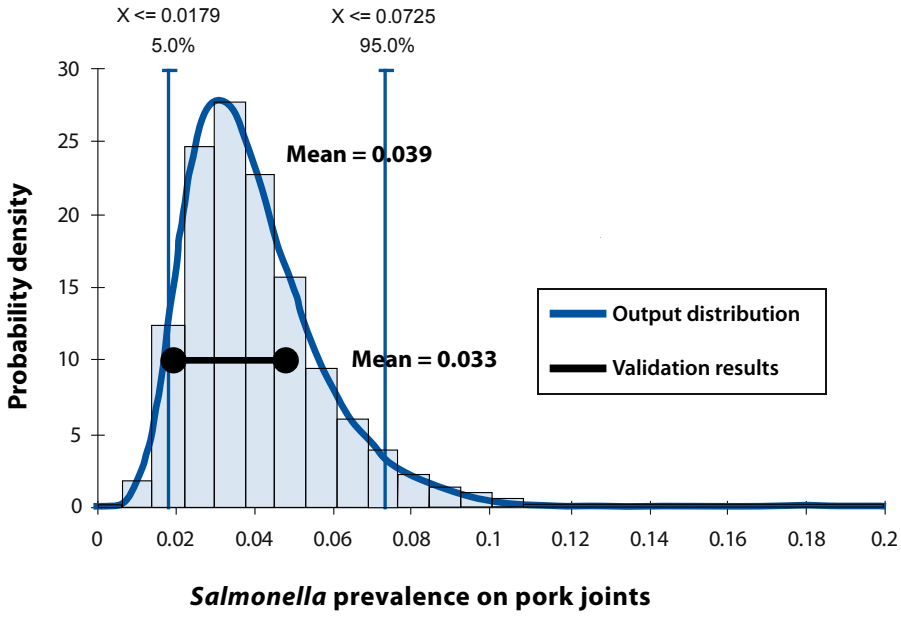

Figure 10: Predicted *Salmonella* Prevalence on Pork Joints in ROI as an output of the risk model and a microbiological study (validation)

In order to assess the accuracy of predictions made by the model, the model output was validated against the microbiological results on *Salmonella* prevalence in pork joints produced in the boning halls of four representative abattoirs conducted in the project (Section 2). The survey as described above reported 24/720 positive samples (3.3% with a 95% CI of 2.02 to 4.64%). The mean values for the simulation (3.9%) and the survey were therefore similar, although the simulated distribution was considerably wider and skewed (Figure 10). In support of the distribution shape found by simulation, a key finding from the validation survey was the substantial variation in the prevalence of *Salmonella* on the different days, either morning or afternoon, ranging from 0 to 6.6%.

Sensitivity analysis

In an attempt to identify the key parameters that influence the model's output, a sensitivity analysis was performed (Figure 11). The sensitivity of the prevalence of *Salmonella* in pork joints to input values was measured by regression, whereby the higher the correlation between the input and the output, the more significant the input is in determining the output's value. The reduction in *Salmonella* prevalence that can be attained at final rinsing and at chilling had a stronger influence on the final prevalence on pork joints than contamination that may occur during splitting or jointing, the number of times the boning plant is cleaned, and the probability of improper cleaning and disinfection). This reassuringly implies that the final rinsing (R=-0.382) and chilling operations (R=-0.221), when properly performed, can play a significant role the reduction and control of carcass contamination in the abattoir. Such observations lead to the reaffirmation that chilling (as previously proposed by Bolton *et al.* (2002)) and final rinsing (as shown by Saide-Albornoz *et al.* (1995) and Quirke *et al.* (2001)), should be regarded as stages in the slaughter process that can reduce the prevalence of *Salmonella* on the final product. On the other hand, focusing on hygiene practices alone during jointing in boning halls would appear to have only a (disappointingly) marginal effect on diminishing the amount of contaminated pork joints produced (-0.030 and 0.019).

A mathematical model is as good as the data it is fed with and, for a more accurate risk assessment model, further research is necessary. Due to a lack of available data from lack of research in certain areas, the main simplifying assumption made in order to develop this model was the correlation between the proportion of pigs carrying *Salmonella* in their caeca and the proportion of *Salmonella*-positive carcasses post-evisceration. Nevertheless, given the good agreement between the model prediction of *Salmonella* prevalence on pork joints, and the results of a parallel surveillance study, it can be said that this preliminary model, integrating input distributions justified by relevant research and surveys, approximates well to the reality of ROI pig abattoirs. The sensitivity analysis showed that the stages of final washing and chilling had strong impact on the prevalence of *Salmonella* on pork joints, meaning that these subsequent processing stages are critical as a means of significantly improving the microbiological quality of pork.

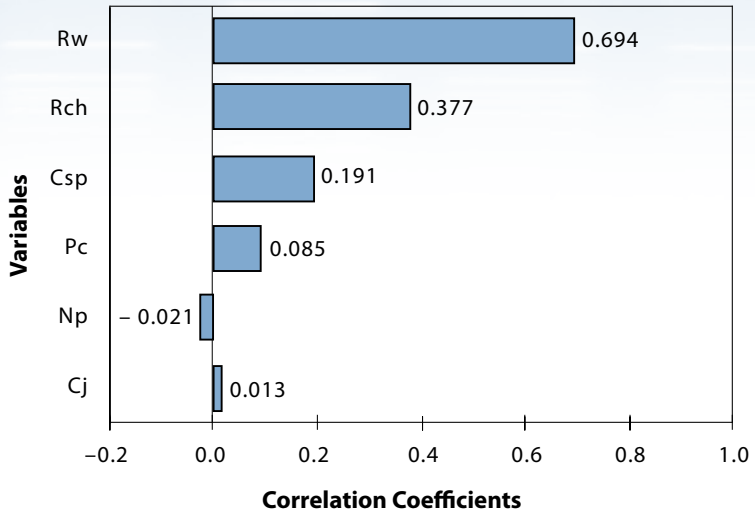

Figure 11: Factors impacting on model prediction for level of *Salmonella* on Pork cuts

(Rw = reduction from washing, Rch = reduction from chilling; Csp = contamination occurring during splitting; Pc = Caecal prevalence; Np = number of times the boning plant is cleaned; cj = contamination from jointing)

Overall the model predicted a linear relationship between the level of *Salmonella* positive pigs coming into a plant for slaughter and the number of contaminated pork cuts at the end of the process. This is a reflection of the potential for a *Salmonella* positive pig coming into the plant to cross contaminate not only its own carcass meat but also that of other pigs and the overall plant environment. It is fully supported by the microbiological data presented earlier in Sections 2 and 3.

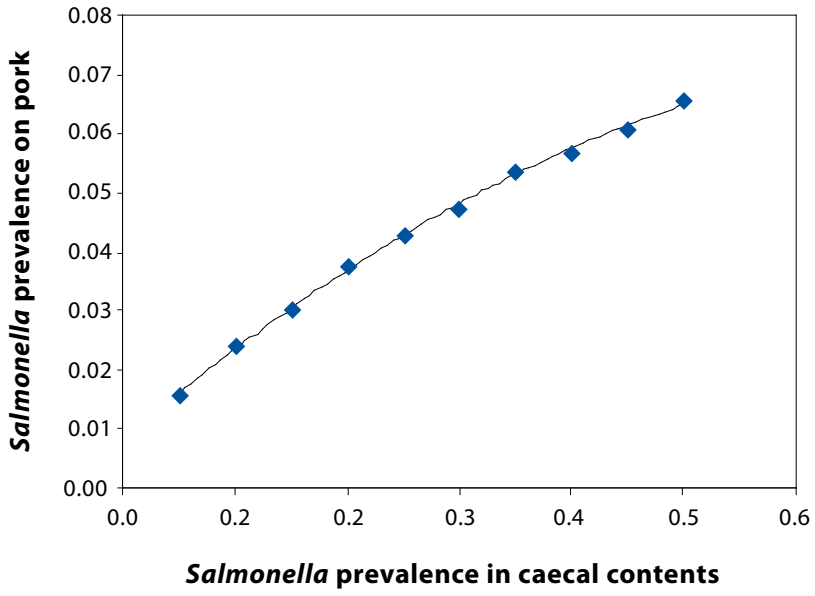

Figure 12: Relationship between *Salmonella* prevalence in pig caecal contents and prevalence in pork cuts at factory level.

Risk assessment model run for NI data

The risk assessment model was then adapted and rerun for NI using input data from this region for *Salmonella* caecal carriage, which the risk assessment model uses as its main input to run the model to predict prevalence of *Salmonella* on pork joints. This input data was based on a study by McDowell *et al.* (2007) who reported that 61/153 (39%) of caecal contents sampled at NI abattoirs tested positive for Salmonella. In order to build an uncertainty distribution for this input, a test sensitivity of 0.85 was used for the protocol reported, and the variable followed a beta distribution.

The simulation model estimated that *Salmonella* prevalence on pork cuts produced in NI was on average 4.5% with a 95% CI of 0.33-12.65% (Figure 13). According to the NI survey of pork oyster cuts in boning halls, an average of 8.3% samples were contaminated, with an incidence 95% confidence interval of 6.31-11.06%. While this figure is within the 95% CI of the simulation's output, it is noteworthy that during the NI sampling, there was a day on which the *Salmonella* contamination was very high (52.5% against 0,0,10, 15, 5, 7.5, 0, 0, 0, 0, 6.6, 10, 6.6, and 3.3% on the other days). If this value were considered as an outlier and therefore, not included in the survey's estimate, the *Salmonella* prevalence on pork cuts would have been 4.9% with a 95% CI of 3.19-7.00%, which comes closer to the simulation's prediction (Figure 13). For comparison, the incidence of *Salmonella* in pork sold at NI retail establishments was found to be 5.5% with a 95% CI of 3.12-9.58%). The results from the model indicate that the true prevalence of *Salmonella* in pork cuts in NI may be closer to the prevalance found in ROI than is indicated by a simple comparison of the results of the boning hall surveys carried out in the two jurisdictions.

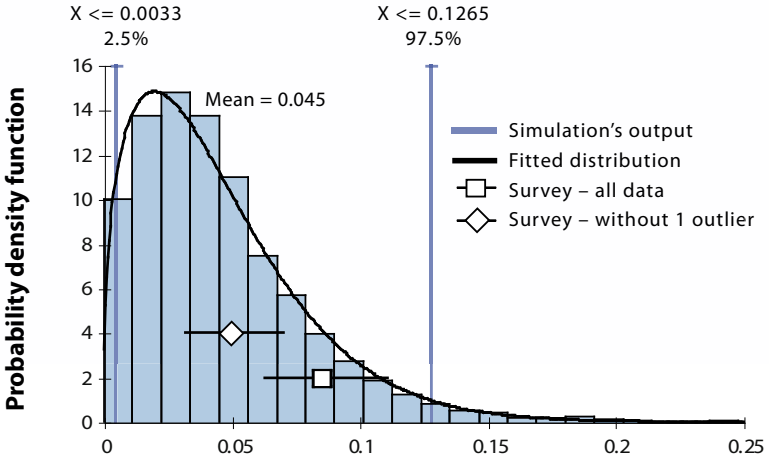

Figure 13. Model output distribution of *Salmonella* prevalence in pork joints estimated for Northern Ireland

5. Answers to risk managment questions

The programme has allowed the risk management questions outlined in Section 3.1 to be answered

1. Is there a difference in consumer exposure to Salmonella via consumption of pork produced in the two jurisdictions?

Salmonella spp. was detected on 24/720 (3.3%) pork cuts sampled at the boning hall and in 13/500 (2.60%) of pork cuts examined at retail in ROI. In NI, *Salmonella* was recovered from 44/525 (8.38%) of pork cuts at boning hall and in (11/200) 5.5% of cuts at retail level. However, these differences are not statistically significant and in both jurisdictions, the key finding was the enormous variation in *Salmonella* prevalence on different sampling days which was observed in samples taken at boning hall and at retail. In both jurisdictions, in the boning halls, the prevalence of *Salmonella* on pork cuts was significantly higher on cuts taken during afternoon production than during morning production. At boning hall and at retail, sub-typing of isolates by PFGE showed evidence of cross contamination of *Salmonella* between different samples. A better understanding of why there is such variability in the incidence of *Salmonella* between factories and on different production days would greatly assist in reducing overall risk. The prevalence of *Salmonella* on pork cuts was also associated with higher *Enterobacteriaceae* counts highlighting the impact of hygiene in pathogen control at retail level.

In ROI, *S.* Typhiumuium (~ 50%) and *S.* Derby (~ 20 %) were the dominant serogroups recovered from pork. Many others serotypes were also recovered and many of these isolates were antibiotic resistant indicating that they would be more difficult to treat clinically. In NI, *S.* Rissen was the dominant serotype recovered, followed by *S.* Typhimurium and *S.* Derby.

2. At pork slaughter, what is the contribution of processing to pork contamination?

Tracking and genetic fingerprinting of *Salmonella* recovered from the pork chain showed that contamination of carcasses and pork cuts could be introduced from the pigs own caecal or rectal contents (faeces) during slaughter and dressing or more commonly through cross contamination from other pigs during transport, lairage, or contact with other contaminated pork cuts, equipment, surfaces etc during processing and distribution. However, while cross contamination was shown to potentially occur at many different stages in the chain, it was highly intermittent and variable. There were very clear differences in the prevalence of *Salmonella* between different factories, and between different days of slaughter. This was evident in both ROI and NI plants. On particular days of operation it was shown that the same *Salmonella* strain could persist on cutting equipment and surfaces throughout a production day contaminating large volumes of pork being processed on that day. On particular days when *Salmonella* prevalence was high, *Enterobacteriaceae* counts were also generally high indicating breakdowns in hygiene and that monitoring of this group of microorganisms could be useful in controlling *Salmonella*.

The research indicates a need to implement measures to reduce cross contamination during transport, lairage, processing and retail levels. An understanding of why there is such variability in cross contamination and incidence of *Salmonella* between factories and on different production days would greatly assist in reducing overall risk.

3. Is there a relationship between the prevalence of Salmonella in the herd and the Salmonella *status of the cut pork?*

Historical serological testing and categorisation was not shown to be a good predictor of the bacteriological *Salmonella* status of an individual pig at the time of slaughter. However, serological testing does help in giving an estimate of the overall *Salmonella* status of a pig herd. The risk model showed a linear correlation between prevalence of *Salmonella* in caecal contents and on pork cuts. Therefore if the number of Category 3 pigs slaughtered was reduced, there would be less potential for contamination of the lairage, equipment etc and so less *Salmonella* on pork.

6. Expert ellicitation study on interventions for *salmonella*

An expert elicitation study was conducted to rank a series of potential management interventions in terms of effectiveness and therefore provide recommendations on which interventions would be most effective.

The expert elicitation study involved experts in the area completing a series of similar questionnaires over time. The study applied a Delphi Methodology, which is concerned with combining the views of experts to arrive at a general consensus of opinions within the group, using a series of three questionnaires. The objective of this study was to rank potential management interventions within the main stages of the supply chain. It was not the intention of the study to guarantee that such interventions would be effective for all stakeholders; the success of each intervention will depend on a number of factors, as is evident from the main barriers impacting the success of interventions in practice, which were identified in this study.

On-Farm Interventions

Monitoring and intervention at farm level is imperative in order to reduce *Salmonella* in pork and associated pork products (Mousing *et al.* 1997). The results from the expert study indicate that the most effective interventions at the on-farm stage of the pork supply chain are (1) Good Agricultural Practices (GAP) and hygiene measures/ all in/all out policies, (2) appropriate feed, and (3) education and awareness. However, in the context of the effectiveness of each of these interventions, experts' comments on the barriers impacting the implementation and utilisation of each intervention in practice are important considerations regarding the feasibility of these interventions.

A significant number of experts expressed concern that the costs involved in utilising GAP and hygiene measures in practice are an important barrier. All in/all out policies allow time for good hygiene practices to take place in addition to minimising the risk of cross contamination and infection, however, inadequate facilities will impact on the success of this intervention according to the experts.

Feed is known to act as a potential source of contamination. The use of appropriate feed (for example meal/wet/non-pelleted/acidified/fermented) is deemed the second most effective intervention to reduce the risk of *Salmonella* at the on-farm stage. However, high feed costs act as a considerable barrier to utilising this intervention in practice. Finally, in the case of education and awareness programmes, resistance, mainly a lack of willingness to change, is noted as a considerable barrier.

Transport/Lairage Interventions

Animals can become infected with *Salmonella* during transport and lairage due to increased stress and handling. Social stress of weaned pigs may increase susceptibility to and/or fecal shedding of *Salmonella* (Callaway *et al,* 2006). Minimising the amount of time that pigs spend in the lairage prior to entering the slaughterhouse is deemed by the experts to be the most effective intervention at this stage. It has the potential to reduce stress and thus shedding of *Salmonella* which may be transferred to Salmonella-free animals. However, a considerable barrier to this intervention is logistical and just-in-time delivery difficulties which may impact on holding times.

A number of experts commented that the lairage acts as a significant source of infection for pigs entering the abattoir. Consequently, improved cleaning of the lairage has the potential to reduce/prevent cross contamination. This was ranked second in terms of effectiveness at this stage by the group of experts. However, inadequate facilities and resources are a barrier to this intervention.

The third most effective intervention identified for this stage of the supply chain is separating herds from different farms to avoid stress and separating different Category herds through to slaughtering. Separating herds from different farms to avoid stress has the potential to reduce the risk of spread in addition to reducing the risk of contaminating non-infected pigs. However, inadequate lairage designs act as a potential barrier to the success of this intervention in practice. Separating different Category herds through to slaughtering is believed to control the risk and minimise the potential for cross contamination. One expert noted that this intervention has been successful in Denmark where there is a 'dedicated abattoir for Category 3 pigs', arguing that 'if these pigs can be kept separate, the environment becomes less contaminated'. However, experts raised concerns that barriers relating to issues with categorisation and inadequate management/operational techniques may impact the success of this intervention in practice.

Slaughtering/Processing Interventions

At these stages of the pork supply chain, there is great potential for cross contamination to occur. *Salmonella*

infected animals entering this stage have the potential to create cross contamination from animal to the edible tissue of the carcass. The results from the expert study highlight that the top three most effective interventions are (1) careful evisceration, (2) bagging the bung, and (3) logistic slaughter as they have the potential to reduce the risk of carcass/cross contamination. However, the main barrier impacting on the success of careful evisceration and bagging the bung is poor employee training according to the experts. Issues regarding pig herd categorisation (with poor correlation between the historical serological status and the actual *Salmonella* bacteriological status for individual animals at the time of slaughter as shown in this study) can act as a barrier to success of logistic slaughter in practice.

Distribution/Retail/Catering/Consumer Interventions

Produce irradiation has been identified by the experts as the most effective intervention for reducing *Salmonella* prevalence at this stage of the supply chain. However, a significant number of experts expressed concern regarding the success of this intervention in practice, the main concern being securing consumer acceptability. One expert noted that while 'it would be a good intervention for reducing the prevalence of *Salmonella*, it would not be an acceptable symbol to have on the product label'. Furthermore, such an intervention is currently not permitted in EU legislation. Consumer education regarding the risks from cross contamination has been identified as 'a step in the risk reduction process' and as the second most effective intervention. However, ability to effectively reach the target audience is considered a barrier to the success of this intervention in practice. Educating workers regarding the risks from cross contamination is considered an effective intervention that has the potential to ultimately reduce the risk of cross contamination incidents. However, ineffective and/or insufficient training can act as a major barrier.

In conclusion, *Salmonella* has the potential to enter and spread at all stages of the pork supply chain. Management interventions are thus important to attempt to reduce the prevalence of *Salmonella*. A number of experts have emphasised that utilisation of a combination of interventions is imperative; arguably no single intervention in isolation is sufficient. It is thus essential that interventions are developed at all stages of the pork supply chain. One expert in this study commented that 'the EU will in due course implement a "zero-tolerance" regime for *Salmonella*' and that the Irish pork industry will need 'to have implemented the necessary reductions in prevalence or penalties will be applied'. This study provides some insight into potential interventions to reduce the prevalence of *Salmonella* at various stages of the supply chain, and thus the overall costs associated with *Salmonella*. However, it is important that potential barriers impacting the success of interventions in practice are considered.

7. Cost of illness attributed to *Salmonella* on the island of ireland

The incidence of foodborne disease is not well defined in many countries, however, it is becoming increasingly associated with high financial losses to society. Reliable estimates of both the incidence of foodborne illness and its financial impact are essential for informing policy decisions on food safety. In addition to this, knowing the true extent of disease also helps in assessing the effectiveness of any changes to food safety standards and regulations. Therefore the main aims of this assessment was to determine the true extent of salmonellosis for a selected year (2004) on the island of Ireland and to determine the financial losses associated with this disease in the same time period.

The incidence of salmonellosis is estimated and the cost associated with this disease on the island of Ireland in 2004. Reported cases of human salmonellosis from the national surveillance systems in ROI and NI were used in conjunction with a multiplier of disease from a previous study in order to extrapolate the full extent of human *Salmonella* infection on the island of Ireland. Multiple datasets were used in order to calculate the associated direct costs such as hospital visitation costs, GP fees, laboratory examination costs, and indirect costs such as productivity and leisure time costs due to this disease. The data sources ranged from Departments of Health for hospital figures, to statistics resource units in ROI and NI for earnings and labour market participation rates. Cost and incidence data were taken from 2004 as this was the latest year for which all data were available. Productivity losses were calculated by multiplying the price of labour (wage rates) by the number of days of work missed by particular cases. Leisure time losses were calculated in a similar fashion; the price of labour (full wage rate) was multiplied by the number of hours of lost leisure time due to salmonellosis. In addition to these equations, a number of different assumptions had to be made in order to calculate these indirect losses.

Results indicate that approximately 3,655 persons are estimated to have experienced symptoms of acute gastroenteritis as a consequence of infection with *Salmonella* bacteria on the island of Ireland in 2004. It was estimated that there were 2,783, unreported cases whilst 709 patients attended a GP and 162 cases were admitted to hospital with this disease. The total costs-of-illness is estimated at approximately €4.5 million in 2004 for the island of Ireland.

8. Summary conclusions

From the study on the prevalence of *Salmonella* on pork cuts in the boning hall, the, the key finding in both jurisdictions was the enormous variation in *Salmonella* prevalence on different sampling days (0 to 31.6% in ROI and 0 to 52.5 % in NI). In both jurisdictions, the prevalence of *Salmonella* on pork cuts was significantly higher on cuts taken during afternoon production than during morning production. On particular days when *Salmonella* prevalence was high, *Enterobacteriaceae* counts were also generally high indicating breakdowns in hygiene and that monitoring of this group of microorganisms could be a useful indicator in controlling Salmonella. A better understanding of why there is such variability in the prevalence of *Salmonella* between factories and on different production days would greatly assist in reducing overall risk.

The study on the transmission of *Salmonella* at retail level highlighted enormous variation in *Salmonella* prevalence on different sampling days regardless of jurisdiction. There was also evidence from genetic fingerprinting of cross contamination of *Salmonella* between different samples purchased from the same shop. The prevalence of *Salmonella* on pork cuts was also associated with higher *Enterobacteriaceae* counts highlighting the impact of hygiene in pathogen control at retail level. A better understanding of why there is such variability in the prevalence of *Salmonella* between sample days would greatly assist in reducing overall risk.

Tracking the *Salmonella* status of pigs from farm through to boned out cuts highlighted that at an individual pig level there was little correlation between the *Salmonella* serological status and bacteriological status of caecal and rectal contents when the animal was presented for slaughter indicating that logistic slaughter based on this historical data is unlikely to be an effective control strategy.

The study showed that contamination could be transmitted from one contaminated carcass or meat cut to another and that equipment and surfaces play a very important role in cross contamination. There was high variability in cross contamination from day to day and abattoir to abattoir. This study has shown that the lairage was a major source of cross contamination with *Salmonella* as were the hands of evisceration operatives employed in debunging and conveyor belts and equipment in the boning hall. Cross contamination within the slaughter plant environment can account for up to 69% of contamination on carcasses and pork cuts. There was a strong association found between Enterobacteriaecea counts (hygiene indicators) and *Salmonella* status on pre chill carcass swab and also a significant association between Enterobacteriaecea counts and the *Salmonella* status of pork cut samples.

These findings suggest that considerable improvements are possible within the slaughter process, which should reduce carcass contamination levels. However, improvement of the *Salmonella* status of high prevalence herds at pre harvest level would be of significant benefit also as animals from these herds are

ultimately the major source of contamination within the environment of the plant. Overall, results from this study corroborate the EU recommendation that control programmes implement measures at both primary and slaughterhouse level.

Overall the risk assessment model predicted a linear relationship between the level of *Salmonella* positive pigs coming into a plant for slaughter and the number of contaminated pork cuts at the end of the process. This is a reflection of the potential for a *Salmonella* positive pig coming into the plant to cross contaminate not only its own carcass meat but also that of other pigs and the overall plant environment. A conclusion which is fully supported by the microbiological data.

In conclusion, *Salmonella* has the potential to enter and spread at all stages of the pork supply chain and therefore control must involve a farm to fork approach. A general consensus among an expert group asked to suggest and comment on potential interventions was that the utilisation of a combination of interventions is imperative; with no single intervention likely to have a risk reduction impact in isolation. There are many potential barriers impacting the success of interventions in practice and that cost and safety will always be comprised against each other. This highlights the need to combine risk modelling (which can predict risk reduction) with cost benefit analysis for potential interventions.

9. References

Abrahim, A., Papa, A., Soultos, N., Ambrosiadis, I. and Antoniadis, A. (1998) Antibiotic resistance of *Salmonella* spp. and *Listeria* spp. isolates from traditionally made fresh sausages in Greece. *J. Food Prot.* 61, 1378-1380.

Alban, L., and Stark, K.D.C. (2005) Where should the effort be put to reduce the *Salmonella* prevalence in the slaughtered swine carcass effectively? *Prev. Vet. Med.* 68, 63-79.

Anonymous. (2005b) The community summary report on "trends and sources of zoonoses and zoonotic agents in humans, antimicrobial resistence and foodborne outbreaks in the European Union in 2005". *The EFSA Journal, 94.* Available from: http://www.efsa.europa.eu/etc/medialib/efsa/science/monitoring_zoonoses/reports/zoonoses_report_2005.Par.0001.File.dat/Zoonoses_report_2005.pdf

Bager, F., Emborg, H.D., Sorensen, L.L., Halgaard, C. and Jensen, P.T. (1995) Control of *Salmonella* in Danish pork. *Fleischwirtschaft,* 75, 1000-1001.

Beloeil, P. A., Chauvin, C., Proux, K., Madec, F., Fravalo P. and Aliom, A. (2004) Impact of the *Salmonella* status of market-age pigs and the pre-slaughter process process on *Salmonella* caecal contamination at slaughter. *Vet. Res.* 35, 513-530.

Berends, B. R., F. Van Knapen, J. M. A. Snijders and D. A. A. Mossel. (1997) Identification and quantification of risk factors regarding *Salmonella* spp. on pork carcasses. *Int. J. Food Microbiol.* 36, 199-206.

Berends, B.R., Van Knappen, F. and Snijders, J.M.A. (1998) *Salmonella* spp. on pork at cutting plants and at the retail level and the influence of particular risk factors. *Int. J. Food Microbiol.*, 44, 207-217.

Bolton, D. J., R. A. Pearce, J. J. Sheridan, I. S. Blair, D. A. McDowell and D. Harrington. (2002) Washing and chilling as critical control points in pork slaughter hazard analysis and critical control point (HACCP) systems. *J. Appl. Microbiol* 92, 893-902.

Boughton, C., Leonard, F.C., Egan, J., Kelly, G., O'Mahony, P., Markey, B.K. and Griffin, M. (2004) Prevalence and number of *Salmonella* in Irish retail pork sausages. *J. Food Protect*. 67, 1834-1839.

Bouvet, J., C. Bavai, R. Rossel, A. Le Roux, M. P. Montet, C. Mazuy and C. Vernozy-Rozand. (2003) Evolution of pig carcass and slaughterhouse environment contamination by *Salmonella. Revue de Medicine Veterinaire* 154, No.12, 775-779.

Botteldoorn, N., Heyndrickx, N., Rijpens, N, Grijspeerdt, K and Herman, L., (2003) *Salmonella* on pig carcasses: positive pigs and cross contamination in the slaughterhouse. *J. Appl. Microbiol*., 95, 891-903.

Boyen F., Haesebrouch, F., Maes, D., Van Immerseel, F., Ducatelle, R., Pasmans, F. (2008) Non typhoidal *Salmonella* in pigs: a closer look at epidemiology, pathogensis and control. *Vet. Microbiol.* 130 1-9.

Callaway TR, Morrow JL, Edrington TS, Genovese KJ, Dowd S, Carroll J, Dailey JW, Harvey RB, Poole TL, Anderson RC, Nisbet DJ. (2006). Social stress increases fecal shedding of *Salmonella* Typhimurium by early weaned piglets. *Curr Issues Intest Microbiol.* 7, 65-71.

Casey, P. G., D. Butler, G. E. Gardiner, M. Tangney, P. Simpson, P. G. Lawlor, C. Stanton, R. P. Ross, C. Hill and G. F. Fitzgerald. (2004). *Salmonella* carriage in an Irish pig herd: correlation between serological and bacteriological detection methods. *J. Food Prot.* 67, 2797-2800.

Clark, M. (2006) *Salmonella* blog: Surveillance and analysis on *Salmonella* news and outbreaks. Tibaldi pork recalled. Available from: http://www.Salmonellablog.com/2006/06/articles/Salmonella-recalls/tibaldi-pork-recalled/

Clark, M. (2007) *Salmonella* blog: Surveillance and analysis on *Salmonella* news and outbreaks. *Salmonella* outbreak traced to pulled pork. Available from: http://www.Salmonellablog.com/2007/12/articles/Salmonella-outbreaks/Salmonella-outbreak-traced-to-pulled-pork

Clark, M. (2008) *Salmonella* blog: Surveillance and analysis on *Salmonella* news and outbreaks. Crackling pork recalled due to *Salmonella* contamination. Available from: http://www.Salmonellablog.com/articles/Salmonella-recalls/

Davies, R. H., I. M. McLaren and S. Bedford. (1999) Distribution of *Salmonella* contamination in two pig abattoirs. In: *Proceedings of the 3rd International Symposium on the Epidemiology and Control of Salmonella in Pork* (Washington, Aug. 4-7) 267-272.

Davies, R. H., R. Dalziel, J. C. Gibbens, J. W. Wilesmith, M. B. Ryan, S. J. Evans, C. Byrne, G. A. Paiba, S. J. S. Pascoe and C. J. Teale. (2004) National survey for *Salmonella* in pigs, cattle and sheep at slaughter in Great Britain (1999-2000). *J. Appl Microbiol.* 96, 750-760.

Duggan, S.J., Mannion, C., Prendergast, D.M. , Leonard, N., Fanning, S. , Gonzales-Barron, U., Egan, J., Butler, F. and Duffy, G. (2009) Tracking the *Salmonella* status of pigs through the slaughter process in the Republic of Ireland. *J. Food Prot. (in press)*

Duffy E.A., Belk K.E., Sofos J.N., Bellinger, G.R., Pape, A. and Smith G.C. (2001) Extent of microbial contamination in United States pork retail products. *J. Food Prot.* 64, 172-178.

Duffy, G., Cloak, O.M., O'Sullivan, M.G., Guillet, A., Sheridan, J.J., Blair, I.S. and McDowell, D.A. (1999). The incidence and antibiotic resistance profiles of *Salmonella* spp. on Irish retail meat products, *Food Microbiol.* 16: 623-631.

European Centre for Disease Control and Prevention (ECDC). (2008) Update on an outbreak of *Salmonella* Agona in Ireland and other EU countries. Available at: http://www.ecdc.europa.eu/en/health_content/Articles/article_20080918.aspx

Foley, B., McKeown, P., de Lappe, N. and Cormican, M. (2007) Salmonellosis in Ireland, 2007. Epi-Insight 8, 2-3. Available at: http://www.ndsc.ie/hpsc/EPI-Insight/Volume82007/

Gareis, M., Rotheneder, R. and Hechelmann, H. (1996) Occurrence of *Salmonella* spp. in the pork production line. *Fleischwirtschaft,* 76, 1329-1240.

Gonzales-Barron, U., Soumpasis, I., Butler, F., and Duffy, G. (2008a) A comparison between herd-level and animal-level simulation for estimation of prevalence of *Salmonella* in caecal contents of slaughter pigs in Ireland from meat juice serology. *Risk Analysis. (in press)*

Gonzales Barron, U., Bergin, D. and F. Butler (2008b) A meta-analysis study of the effect of chilling on *Salmonella* prevalence on pork carcasses. *J. Food Prot,* 71, 1330 – 1337.

Gonzales Barron, U., Soumpasis, I., Butler, F., Duggan S., Prendergast, D., and Duffy, G. (2009a) Estimation of prevalence of *Salmonella* spp. on pig carcasses and pork joints using a quantitative risk assessment model aided by meta-analysis. *J. Food Prot*., 72, 274-285.

Gonzales Barron, U., Soumpasis, I., and Butler, F. (2009b) An appraisal of the use of meat juice serology monitoring data for estimating prevalence of caecal *Salmonella* carriage of pigs at slaughter by means of herd-level and animal-level simulation. *J. Food Prot,* 72, 286-294.

Hald, T., A. Wingstrand, M. Swanenburg, A. von Altrock and B. M. Thorberg. (2003) The occurrence and epidemiology of *Salmonella* in European pig slaughterhouses. *Epidemiol. and Infect.* 131, 1187-1203.

Hurd, H.S., McKean, J.D., Wesley, I.V. and Karriker, L.A. (2001) The effect of lairage on *Salmonella* isolation from market swine. *J. Food Prot.* 64, 939-944.

Hurd HS, McKean JD, Griffith RD, Rostagno MH. (2004) Estimation of the *Salmonella* enterica prevalence in finishing swine. *Epidemiol Infect.* 32, 127-35.

Ishizaki, N., Kaneko, S., Itoh, T., Jinbo, K., Kataoka, J., Kokubo, Y., (1993). The detection and serotyping of *Salmonella* from commercial meat from 1989 to 1992 in Tokyo. Annual Report of Tokyo Metropolitan Research Laboratory of Public Health. 44,101–104.

Jansen, A., Frank, C., Prager, R., Oppermann, H. and Stark, K., 2005. Nation-wide outbreak of *Salmonella* Give in Germany, 2004. Z. *Gastroenterol*, 43, 707 – 13.

Jayarao BM, Biró G, Kovács S, Domján H, Fábián A. (1989) Prevalence of *Salmonella* serotypes in pigs and evaluation of a rapid, presumptive test for detection of *Salmonella* in pig faeces. *Acta Vet Hung*. 37, 39-44.

Jordan, E., Egan, J., Dullea, C., Ward, J., McGillicuddy, K., Murray, G., Murphy, A., Bradshaw, B., Leonard, N., Rafter, P. and McDowell, S., (2006) *Salmonella* surveillance in raw and cooked meat and meat products in the Republic of Ireland from 2002 to 2004. *Int. J. Food Microbiol.* 112, 66-70.

Kishima, M., Uchida, I., Namimatsu, T., Osumi, T., Takahashi, S., Tanaka, K., Aoki H, Matsuura, K. and Yamamoto, K. (2008) Nationwide surveillance of *Salmonella* in the faeces of pigs in Japan. *Zoonoses public health,* 55, 139-144.

Kranker, S., L. Alban, J. Boes and J. Dahl. (2003) Longitudinal study of *Salmonella* enterica serotype Typhimurium infection in three Danish farrow-to-finish swine herds. *J. Clinical Microbiol.* 41, 2282-2288.

Letellier A, Messier S, Quessy S. (2001). Prevalence of *Salmonella* spp. and Yersinia enterocolitica in finishing swine at Canadian abattoirs. *J. Food Prot.* 62, 22-5.

Lima, E. S., P. S. Pinto, J. L. Santos, M. C. Vanetti, P. D. Bevilacqua, L. P. Almeida, M. S. Pinto and F. S. Dias. (2004). Isolamento de *Salmonella* sp. e Staphylococcus aureus no proceso do abate suíno como subsídio ao sistema de análise de perigos e pontos críticos de controle – APPCC *Pesquisa Veterinária Brasileira* 24, 185-190.

Luzzi, I., Galetta, P., Massari, M., Rizzo, C., Dior Cawthorne, AM, Tozzi, A., Argentieri, M., Bilei, S., Busani, L., Gnesivo, C., Napoli, A., Loffredo, R., Trinito, M.O., Sanatarelli, E., Ciofi degli, Atti, ML (2007). An easter outbreak of *Salmonella* Typhimurium DT104A associated with a traditional pork salami in Italy. *Eurosurveillance* Vol 12, Issue 4.

Mannion, C., J. Egan, P. Lynch, S. Fanning and N. Leonard (2008) An investigation into the efficacy of washing trucks following transportation of pigs – a *Salmonella* perspective. *Foodborne pathogens and disease* 5, 261-271.

McDowell SW, Porter R, Madden R, Cooper B and Neill, S.D. (2007) *Salmonella* in slaughter pigs in Northern Ireland: prevalence and use of statistical modelling to investigate sample and abattoir effects. *Int. J. Food Microbiol.* 118, 116-125.

Morgan, I. R., F. L. Krautil and J. A. Craven. (1987) Effect of time in lairage on caecal and carcass *Salmonella* contamination of slaughter pigs. *Epidemiol. and Infect.* 98, 323-330.

Mousing J, Jensen PT, Halgaard C, Bager F, Feld N, Nielsen B, Nielsen JP, Bech-Nielsen S. (1997) Nation-wide *Salmonella* enterica surveillance and control in Danish slaughter swine herds. *Prev Vet Med.* 29, 247-61.

Murase, T., Yamada, M., Matsusihima, T. and Yamai, S. (2000). Fecal excresion of *Salmonella* enterica serovar Typhimurium following a food-borne outbreak. *J. Clinical Microbiol.*, 38, 3495-3497.

Epi-insight, Disease Surveillance Report of the National Disease Surveillance Centre, Ireland (2001). *Salmonella* infection in Ireland. Vol, 2, issue 9, Pg 2

Ng, D.P.K., Goh, K.T., Yeo, M.G.C. and Poh, C.L. (1997) An institutional outbreak of *Salmonella* enteriditis in Singapork. *Southeast Asian J Trop Med Public Health*, 28, 85-90.

Oosterom, J., R. Dekker, G. J. A. de Wilde, F. van Kempen-de Troye and G. B. Engels. (1985) Prevalence of *Campylobacter jejuni* and *Salmonella* during pig slaughtering. *The Vet. Quarterly* 7, No. 1, 31-34.

Quirke, A. M., N. Leonard, G. Kelly, J. Egan, P. B. Lynch, T. Rowe and P. J. Quinn. (2001) Prevalence of *Salmonella* serotypes on pig carcasses from high- and low-risk herds slaughtered in three abattoirs. *Berlin Munich Tierarztlung und Wissenschaft* 114, 360-362.

Pearce, R. A., D. J. Bolton, J. J. Sheridan, D. A. McDowell, I. S. Blair and D. Harrington. (2004) Studies to determine the critical control points in pork slaughter hazard analysis and critical control point systems. *Int. J. Food Microbiol.* 90, 331-339.

Prendergast DM, Duggan SJ, Fanning S, Cormican M, Gonzales-Barron U, Butler F, Duffy G. (2008) Prevalence and numbers of *Salmonella* spp. and *Enterobacteriaceae* on pork cuts in abattoirs in the Republic of Ireland. *J. Appl. Microbiol.* 105, 1209-1219.

Prendergast DM, Duggan SJ, Gonzales-Barron U, Fanning S, Butler F, Cormican M, and Duffy G. (2009). Prevalence, numbers and characteristics of *Salmonella* spp. on Irish retail pork. Int. *J. Food Microbiol.* 131, 233-239.

Rajic, A. and Keenliside, J. (2001) *Salmonella* in swine. *Adv. Pork Prod.*, 12, 35-41.

Van Pelt, W., and S. M. Valkenburgh (ed) (2001) Zoonoses and zoonotic agents in humans, food, animals and feed in the Netherlands. Inspectorate for Health Protection and Veterinary Public Health, The Hague, The Netherlands.

Saide-Albornoz, J., C. L. Knipe, E. A. Murano and G. W. Beran. (1995). Contamination of pork carcasses during slaughter, fabrication and chilled storage. *J. Food Prot*. 58, 993-997.

Sorensen, L. L., L. Alban, B. Nielsen and J. Dahl. (2004). The correlation between *Salmonella* serology and isolation of *Salmonella* in Danish pigs at slaughter. *Vet. Microbiol.* 101, 131-141.

Stege, H.J., Christensen, J., Nielsen, J.P. Bagesen, D.L., Enoe, C. And Willeberg, P. (2000) Prevalence of subclinical *Salmonella* enterica infection in Danish finishing pig herds. *Prev. Vet. Med.* 44, 175-188.

Swanenburg, M., H. A. P. Urlings, J. M. A. Snijders, D. A. Keuzenkamp and F. van Knapen. (2001). *Salmonella* in slaughter pigs: prevalence serotypes and critical control points during slaughter in two slaughterhouses. *Int. J. Food Microbiol.* 70, 243-254.

Zhao, C., Beilei, G.E., de Villena, J., Sudler, R., Yeh, E., Zhao, S., White, D.G., Wagner, D. and Meng, J. (2001) Prevalence of *Campylobacter* spp., *Escherichia coli* and *Salmonella* serovars in retail chicken, turkey, pork and beef from the Greater Washington DC area. *Appl. Envirion. Microbiol.* 67, 5431-5436.