A review of current knowledge on *Salmonella* control on-farm and within the processing plant relevant to the Northern Ireland pig industry

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Executive Summary

There are many areas where *Salmonella* prevalence could be reduced throughout pig production and processing and a whole chain approach is required. This literature review has highlighted that there are several factors associated with *Salmonella* presence on-farm and that there is an urgent need to identify the point of infection on Northern Ireland farms to enable known effective control measures to be implemented. It has also shown that the serological ELISA test is useful in providing information of *Salmonella* presence on-farm but that it is of limited use in identifying high-risk pigs at slaughter. A recommendation of this literature review is to identify a list of factors associated with *Salmonella* prevalence on-farm in order of priority – this will be completed through a comprehensive producer questionnaire. It is also planned to identify the point of infection on Northern Ireland farms through the completion of a longitudinal study. Once these tasks have been conducted, intervention control measures will be assessed.

Within the processing plant the *Salmonella* carriage at time of slaughter will be quantified to define the prevalence in Northern Ireland herds and also indicate if some pigs present a significantly higher risk than others. The Slaughterhouse Hygiene Tool will be used and correlated with actual microbial contamination. This exercise will provide information on where to target intervention control measures and will ultimately reduce the risk of *Salmonella* contamination within pork products.

Recommendations for on-farm research

- To identify the point of infection on NI farms through scientific longitudinal studies on representative farms. This will be achieved through the use of ELISA testing of blood samples from sows and pigs from weaning to slaughter and through bacteriological testing of faecal samples.
- To identify factors which contribute to *Salmonella* prevalence on-farm. The literature indicates that these factors can be identified through the use of a comprehensive producer questionnaire and listed in order of priority through the development of a statistical model.
- To develop and validate targeted on-farm control strategies to reduce *Salmonella* prevalence. The strategies will be focussed on the point of infection identified from the longitudinal studies and on modifying management practices which influence *Salmonella* infection identified through the questionnaire.

Recommendations for processing plant research

- To establish the bacterial status of herds entering the processing plants by direct faecal sampling of gut contents on the processing line and to compare

with the results of the longitudinal farm studies to further define the apparent point of infection.

- To investigate the level of carcass contamination within the two main processing plants in Northern Ireland and to assess the hygiene throughout the processing line.
- To correlate carcass contamination and processing line hygiene with the level of risk modelled by the Hygiene Tool.
- To introduce effective control measures and interventions at high risk points throughout the line. Ultimately the actual focus areas will be identified by the investigation to determine the level of carcass contamination and hygiene status throughout the line.

Introduction

Human *Salmonellosis* is a common bacterial infection in the UK with approximately 15,000 reported cases and an estimated 45,000 unreported cases per annum (DEFRA, 2007; Wheeler *et al*., 1999). While this level of *Salmonellosis* occurrence does not appear alarming, the condition has been reported to result in 15,000 days in hospital and 200 deaths each year (Adak *et al.,* 2005). Illness can range from a mild to severe gastroenteritis and in some people, invasive disease, which can be fatal. Long term consequences such as reactive arthritis can also result from *Salmonella* infections. The main *Salmonella* serovar found in pigs is *Salmonella* Typhimurium which was responsible for 13.6% of reported *Salmonellosis* cases in the UK (DEFRA, 2007). However, as *Salmonella* Typhimurium is also found in other foods including beef, dairy, lamb and poultry products as well as some herbs and spices it is difficult to specifically quantify the proportion of *Salmonellosis* in UK cases that are directly related to contaminated pig products (Snary *et al.,* 2010; DEFRA, 2007). Nevertheless, the role of pork and pork products in causing human *Salmonellosis* has been quantified for other countries - 22% of cases in the Netherlands and 14% of cases in Denmark (EFSA, 2006). It is reasonable to assume that similar proportions of human *Salmonellosis* can be attributed to pork and pork products within the UK. *Salmonella* is an important cause of foodborne disease in humans throughout the world and is a significant cause of morbidity, mortality and economic loss. The control of *Salmonella* and other specified foodborne agents, which may pose a public health risk, is considered under Commission Regulation (EC) No 2160/2003 (EC, 2003). As part of this regulation, the Commission sets targets for the reduction of *Salmonella* at the level of primary production and where appropriate at other stages of the food chain. Many countries have introduced *Salmonella* control programmes and the EC regulation made control programmes mandatory in 2003. The EU are currently gathering information and drafting proposals for a new *Salmonella* strategy across Europe.

Salmonella is a genus of gram-negative, aerobic, rod-shaped bacteria that can infect people, birds, reptiles, and other animals. Currently the genus *Salmonella* is divided into two species: *Salmonella* enterica and *Salmonella* bongori. The species *Salmonella* enterica consist of six subspecies: S. enterica, S. salamae, S. arizonae, S. diarizonae, S. houtenae and S. indica whereas no subspecies has been assigned to *Salmonella* bongori (Su and Chiu, 2007). Based on the combination of bacterial surface-antigens the genus *Salmonella* is subdivided into 2,541 serovars (also called

serotypes). For convenience the serovars are denominated by genus and serovar only (e.g. *Salmonella* enterica, subspecies enterica, serovar Typhimurium is called *Salmonella* Typhimurium). According to Popoff *et al.* (2004) 1,504 serovars belong to *Salmonella* enterica, subspecies enterica. Most zoonotic serovars associated with human illness are in this group. All *Salmonella* serovars are considered potentially pathogenic for humans, but the degree of host adaptation varies, which affects the pathogenicity.

Current *Salmonella* control programmes for pork production

Salmonella control programmes are based on bacteriological or serological testing or a combination of both. Bacteriological methods express the actual infection status of the animal, including recent transmission or contamination and detect all serovars. The actual infectious agent (or, in the case of multiple infections, agents) is isolated, which makes further characterisation (e.g. serovar and antimicrobial resistance profile) possible. Serological or immunological methods identify previous exposure by detecting the presence of specific antibodies against *Salmonella* using ELISA. This method can identify carriers or animals that are already clear of infection. It detects only those (most common) serogroups (O-antigens) included in the test and therefore new emerging serovars may not be detected (Forshell and Wierup, 2006). Serology indirectly reflects exposure to *Salmonella* and therefore indicates different serologic stages including pigs that are no longer harbouring the bacteria, carriers and shedders. On the other hand, serology might overlook pigs that have been exposed but did not seroconvert. Seroconversion is the development of detectable specific antibodies to microorganisms in the serum as a result of infection or immunisation. Serology (the testing for antibodies) is used to determine antibody positivity. Prior to seroconversion, the blood tests seronegative for the antibody; after seroconversion, the blood tests seropositive for the antibody.

Denmark

There are several aspects to the Danish *Salmonella* control programme which include mandatory testing of feeds and feedstuffs and monitoring the serological and bacteriological prevalence across breeding/multiplier and finishing herds (Wray, 2001). A *Salmonella* Index is calculated based on results from mixed-antigen ELISA tests of blood or meat juice samples. The index is calculated from the number of samples seropositive (i.e. over an optical density (OD) 10%) within the previous three months on a weighted basis (0.6, 0.2 and 0.2). For breeding/multiplier herds, if the index is greater than 5, faeces from pens are collected for bacteriological sampling and if greater than 15, a ban on pig sales to other farms is imposed until the prevalence is lowered. For finishing herds, meat juice samples are taken at slaughter (from 60, 75 or 100 carcasses per annum depending on herd size) and the index calculated. Level 1 herds are those with a low prevalence (<40%), level 2 herds are those with moderate prevalence (<70%) and level 3 herds are those with high prevalence (>70%) (Kranker *et al*., 2003). Penalties are applied to level 2 and 3 herds – a 2% and 4% reduction in final payment respectively. In addition, pigs from level 3 herds must be slaughtered at a designated establishment and the carcasses heat treated or treated in a special manner to reduce the risk of *Salmonella* contamination. If a herd has been designated as level 2 or level 3, there must be follow-up bacteriological testing carried out to establish the serovar present on-farm. If *Salmonella*

Typhimurium DT104 is isolated, the farm is placed under restriction with carcasses treated as level 3 and there is a requirement for special handling of slurry.

Five carcasses are also swabbed daily at the factory in order to determine the *Salmonella* status within the factory.

In 2006-2007, the *Salmonella* prevalence of carcasses in Danish slaughter factories was 3.3%, as measured by bacteriological testing of carcass swabs (EFSA 2008). For the same period, the observed seroprevalence for *Salmonella* (i.e. tested by serological ELISA) was 7.1% (EFSA 2008).

United Kingdom

The original UK *Salmonella* Control programme was introduced in 2002 and was based on the Danish ELISA testing system (Snary *et al*., 2010). The programme, named Zoonoses Action Plan (ZAP) differed from the Danish control programme in that there was no requirement for testing of feeds, testing of breeding/multiplier herds and no requirement for follow-up microbiological testing. There were also no penalties implemented against units with high ZAP status. ZAP required that at least 15 carcasses were selected from each farm every three months (3-5 monthly) and serological testing of meat juice conducted by ELISA. The ELISA test used (Vet-sign) differed from the Danish ELISA test (Salmotype® Pig Screen) and therefore the serological *Salmonella* prevalence results cannot be directly compared. Ring testing of ELISA methods (Van der Heijden, 2001) has shown that the tests have relative sensitivity and the Vet-sign cut-off point (S/P ≥0.25) was similar to the then Danish cut-off point of OD% 40. ZAP level 1 herd were those with <50% of samples positive, ZAP level 2 pigs were those with between 50 and 75% of samples positive and ZAP level 3 pigs were those with ≥75% of samples positive. Unlike the Danish system, there is no weighting applied and the ZAP status was simply an average of the 3 month period. Also, no special treatment of pigs from level 3 farms was required. In 2008, the UK introduced a new control programme (Zoonoses National Control Programme (ZNCP)) which was designed to reduce seroprevalence on-farm. ZNCP is essentially the same as the ZAP programme but there are some key differences. The S/P cut-off ratio for positive samples was lowered to ≥0.10 to make the test more sensitive. This change in sensitivity makes it impossible to compare previous levels with current levels but is necessary to ensure improvement of the programme. Without an increase in sensitivity, it would be necessary to screen increasingly large numbers of samples, whereas making the test more sensitive has meant sample numbers can remain the same (Wegener *et al*., 2003). Other key differences are that farms no longer have to be categorised into levels; all farms must have an action plan in place and that the prevalence is now calculated on a 12 month rolling average.

The UK prevalence of *Salmonella* as isolated from carcasses swabbed at the factory was reported to be 13.5% in 2006-2007 and the seroprevalence as determined by ELISA was reported to be 23.2% (EFSA, 2008).

Ireland

The Irish National Pig *Salmonella* Control Programme is very similar to the Danish programme expect that there is no requirement to categorise farms. All herds must have an on-farm *Salmonella* control programme and must have a % prevalence established. Each farm must have at least 6 meat juice samples taken from slaughter

pigs every month and as for Denmark, the *Salmonella* status is calculated on a weighted average of the previous three month results (0.6, 0.2 and 0.2). If seroprevalence is greater than 50% for the previous 3 results (3x3 months), then the farm will lose its quality assurance status and thus incur financial penalties. Also, follow-up bacteriological sampling must be conducted on-farm to establish the serovar of *Salmonella* present and pigs from these high prevalence farms will be separated in lairage and slaughtered at the end of the day. At the factory, carcasses are swabbed and if prevalence is higher than 10%, the factory must implement the following:

a) Conduct an in-depth HACCP review
b) Increase sampling on the slaughter line in accordance with Microcriteria Regulation 2073/2005
c) Increase sanitation measures
d) Implement specific measures relating to pigs sources from herds with seroprevalence of >50%
e) If no improvement is observed with above measures, increase manning levels on-line and/or slow the slaughter line
f) Heat treatment of high risk body parts

According to EFSA (2008), the prevalence of *Salmonella* on carcasses swabbed at the slaughtering plant is higher than average at 20% for 2006-2007. The seroprevalence for the same period was reported to be 10.1%.

Finland

The Finnish control programme aims to maintain the annual prevalence of *Salmonella* below 1% and has been jointly organised through voluntary measures and mandatory regulations since the 1960s. The programme is based on random bacteriological testing of 3000 sows, 3000 fattening pigs and 3000 meat samples per annum. If *Salmonella* is detected, legislative measures are taken including, epidemiological identification of serovar, restrictions on sales or purchases of pigs and products, disinfection procedures and special arrangements for slaughter (Maijala *et al*., 2005). The Finnish programme also implements a number of other control measures including, *Salmonella* testing of feedstuffs, removal of positive pigs from the production chain, avoiding cross-contamination from positive slurry to feed, fields and housing and the use of all in/all out production systems. Overall, the control programme is very effective with *Salmonella* prevalence at less than 1% although the scheme is expensive. However, it has been estimated that for every Euro invested in the scheme there is a return of between 5.4-258.1 Euros (Maijala *et al*., 2005) and Peltola *et al.* (2001) reported that consumers are willing to invest on average 5.8 Euros per month to maintain the *Salmonella* scheme for meat and eggs.

Finland did not participate in the study reported by EFSA (2008).

Sweden

Like the Finnish programme, the Swedish control programme has been in operation for over 30 years and *Salmonella* is present at very low levels (Wray, 2001). There is *Salmonella* testing of feed and bacteriological sampling of faeces from breeding/multiplier and finishing herds. If *Salmonella* is isolated, the herd is placed under restrictions and compensation is paid to producers.

EFSA (2008) reported that the prevalence of *Salmonella* of carcasses swabbed at the factory was 0% although seroprevalence as tested by ELISA was 18.2%.

On-farm methods of reducing *Salmonella* infection

Wierup (1994) stated that a reduction of the number of human *Salmonellosis* cases can be achieved by a reduction of *Salmonella* infection in pigs. A reduction in on-farm infection can only be realised by understanding the transmission of *Salmonella* on-farm and applying control measures to reduce transmission. In practice, serologically negative swine herds are sometimes found to still produce pigs that are bacteriologically positive in the gut and associated lymph nodes at slaughter (Nollet *et al*., 2005). It has been suggested that these pigs were recently infected, so that the serological response was not fully developed at the time of sampling. However, if some *Salmonella* strains are truly able to actively decrease the immunological response, the current monitoring programmes, which usually are based on serology, may show inadequate in these cases (Boyen *et al*., 2008).

Salmonellosis in pigs is typically asymptomatic and, as such, records of clinical cases are a poor indicator of the overall prevalence of disease. Specific studies undertaken to estimate prevalence are therefore indicated and can serve a number of purposes including predicting the risk of contaminated food products entering the food chain and as a baseline estimate by which to judge subsequent trends or the success of surveillance and control programmes. The proportion of animals positive on caecal culture compared to those positive on serology may reflect genuine differences in the sensitivities of the two techniques but may also reflect the occurrence of recent, and possibly very recent infection, in at least a percentage of animals. The possibility of lairage contamination as a potential source of *Salmonella* positive isolates in caecal contents is also supported by a recent risk factor study, which reported that in pigs which spent 3–6 h in lairage the odds of *Salmonella* in caecal contents was 3.3 times that of pigs that spent less than 3 h, while for pigs that spent more than 6 h, the odds were 13.1 (McDowell *et al*., 2007).

On-farm transmission

It has been traditionally believed that *Salmonella* transmission occurred only through the faecal-oral route and as *Salmonella* is shed in large numbers in the faeces it is accepted that this is the major route of transmission (Wray, 2001). Depending on the inoculation dose, oral experimental infection of pigs with *Salmonella* Typhimurium may result in clinical signs and faecal excretion of high numbers of bacteria (Boyen *et al*., 2008). After infection of the host, *Salmonella* pathogenesis is characterised by three phases: the initial colonisation of the intestine, the invasion of enterocytes, and finally the dissemination to lymph nodes and other organs (Darwin and Miller, 1999). Furthermore, recent results have indicated that following oral exposure of pigs to S. Typhimurium, the bacterium may be isolated from caecal contents within 4-6 h, much more rapidly than previously expected (Fedorka-Cray *et al*., 1995).

Apart from the faecal-oral route, there are several other routes of infections and it is important to consider these also if on-farm control measures are to be effective. The palatine tonsils are often heavily infected in pigs and should, therefore, not be underestimated as a source of *Salmonella* contamination during slaughter (Wood *et al*., 1989). It is generally accepted that *Salmonella* can spread throughout an

organism using the blood stream or the lymphatic fluids and infect internal organs, although this has not yet been studied in swine. The colonisation of the mesenteric lymph nodes, spleen and liver can result in prominent systemic and local immune responses (Dlabac *et al*., 1997). Since this carrier state in pigs is difficult to detect in live animals, either by bacteriological or serological methods (Nollet *et al*., 2005), these pigs can bias monitoring programmes. Stress-induced excretion of *Salmonella* Typhimurium by carrier pigs transported to the slaughterhouse may cause contamination of shipping equipment and holding areas, resulting in pre-slaughter transmission of *Salmonella* to non-infected pigs (Isaacson *et al*., 1999; Boughton *et al*., 2007). Although the mechanism of this stress-induced excretion is not known, there are some indications that catecholamines may play a role. It has been shown that *Salmonella* Typhimurium can ‘‘sense’’ catecholamines and as a result increase its growth rate. Very few researchers have made an attempt to unravel the mechanism of the concealed and prolonged infection in carrier pigs (Wang *et al*., 2007).

There is some evidence from chicken and mice studies that indicate that *Salmonella* can be transmitted through the aerosol route (Darlow *et al*., 1961; Clemmer *et al*., 1960). In recent reports, it was found that airborne *Salmonella* Typhimurium transmission in weaned pigs over short distances is possible, but may be serotype-dependent (Oliveira *et al*., 2006). Rodents, insects and humans are also vectors of *Salmonella* and it has been shown that these are important routes of infection (McChesney *et al*., 1995). Mice faecal pellets have been shown to contain up to 105 cfu *Salmonella* (Henzler and Opitz, 1992). During an investigation of *Salmonella* contamination, which involved 23 pig farms, Davies and Wray (1997) found a wide range of wild animals, that included rats, mice, cats, and birds to be infected. Cats and birds were associated with contamination of feed and grain stores, and rodents were involved in the perpetuation of infection in specific buildings on the farm. In addition, feed and feed ingredients may be contaminated with *Salmonella* and result in infection on-farm. However, there does not appear to be a major problem of *Salmonella* infection through feed in the UK as it has been reported that only 1.9% of 62,470 samples of feed and ingredients were *Salmonella* positive (Report, 1999). Nevertheless, this route of infection should not be ignored and it may be useful to include some assessment of *Salmonella* contamination in feed in future control programmes – with particular emphasis on protein sources. Protein sources, e.g. soyabean meal, are the main source of contamination and a recent study in Sweden isolated *Salmonella* in 14.6% of soyabean meal samples (Wierup and Haggblom, 2010).

Vertical transmission from boars and dams to progeny may also be a route of infection (Davies *et al*., 2000). However, the importance of its role has been questioned as the strategic removal of weaners off-site to clean premises has proven to be successful in reducing *Salmonella* infection (Dahl *et al*., 1997). These workers concluded that the lack of transfer from sows to piglets was either due to an absence of *Salmonella* infection in the sows, or to the low susceptibility of the piglets as a result of antibodies in colostrum.

Maternal antibody transmission is defined as the transfer of antibodies by an immunocompetent (having the normal bodily capacity to develop an immune response following exposure to an antigen) adult, typically a female, to an immunologically naive neonate transplacentally or through colostrum, milk, yolk, etc.

In mammals, antibodies are transferred across the placenta prior to birth and through the colostrums and breast milk postnatally (Ehrlich, 1892). Maternal antibodies may passively protect piglets during the first weeks but these antibodies decrease after a few weeks. When these maternally derived antibodies decrease, piglets are no longer protected and environmental *Salmonella* may contaminate them. In the study "Sensitivity analysis to identify key parameters influencing *Salmonella* infection dynamics in a pig batch", Lurette *et al.* (2009) indicated that partial maternal protection was represented by lowering the probability of infection for piglets during the first four weeks of life.

Control measures

Acidification of feed/water – Friendship *et al.* (2009) reviewed eight relevant papers on acidification and reported that while supplementation was generally beneficial the results were inconsistent. The theory behind the use of acidification to reduce *Salmonella* prevalence is that the supplemental organic acids enter the bacterial cell and dissociate due to the higher pH within the cell. This in turn lowers cellular pH and prevents DNA synthesis and hence replication (Friendship *et al*., 2009). Organic acid can be supplemented via the feed or water although there have been some practical problems associated with water supplementation (i.e. clogging of drinkers and corrosion). Van der Heijden *et al.* (2005), Van der Wolf *et al.* (2001), Hansen *et al.* (1999) and Letellier *et al.* (1999) all supplemented the drinking water of finishing pigs with organic acids. Van der Wolf *et al.* (2001) reported a clear beneficial effect as *Salmonella* seroprevalence was reduced by 65%. Van der Heijden *et al.* (2005) also observed a beneficial effect, however, Hansen *et al.* (1999) and Lettellier *et al.* (1999) did not. There is similar variability on the effect of organic acid supplementation of feed with Papenbrock *et al.* (2005) reporting a 30% reduction in *Salmonella* prevalence in faeces and Walsh *et al.* (2003) reporting no beneficial effect. To further confuse the issue, McLaren *et al.* (2001) found that feed acidification increased the prevalence of *Salmonella* in both weaning and finishing pigs. Despite these inconsistent results, the use of acidification can be recommended as a control measure in some instances although more research is required to understand why it is not effective in all cases.

Feed form – It has been reported by several researchers that offering pigs meal as opposed to pellets significantly reduced *Salmonella* prevalence. The meal results in more acidic conditions within the stomach and this reduces pH and hinders DNA replication within *Salmonella*. The lower pH also promotes the growth of beneficial Lactobacilli bacteria which can competitively exclude *Salmonella* (Prohaszka *et al*., 1990). O'Conner *et al.* (2005), Lettelier *et al.* (2003), Hansen *et al.* (2001), Jorgensen *et al.* (1999) and Kjeldsen and Dahl (1999) all reported that *Salmonella* prevalence was lower in pigs offered meal diets in contrast to those offered pelleted diets. However, Bysted (2003) and Kjaersgaard *et al.* (2001) did not observe any significant difference between sows offered either meal or pellets and Jorgensen *et al.* (2003) actually found that pelleting reduced the proportion of *Salmonella* seropositive pigs (although it must be noted that this was for an "optimised" pelleted diet). As the majority of literature indicated that offering meal instead of pellets can reduce *Salmonella* prevalence, this is a control measure which should be considered. However, it must be highlighted that offering meal can increase feed wastage, thereby reducing feed efficiency and hence increasing the cost of production (Walker *et al*., 1993).

Fermented liquid feeding has been reported to cause a reduction in the pH of the stomach thereby reducing *Salmonella* (Mikkelson and Jensen, 2000). The positive effect of fermented liquid feed has been demonstrated by many researchers (Lo Fo Wong *et al.,* 1999; Dahl 1998; Van der Wolf *et al.,* 1998) although some researchers were unable to demonstrate a beneficial effect (e.g. McLaren *et al*., 2001; Van Winsen *et al*., 2001). It must also be stressed that liquid feeding without fermentation may increase *Salmonella* prevalence and this should be considered if moving from a dry feeding system (Rajic *et al*., 2007; Van der Wolf *et al*., 1999).

Feed type – There is some evidence to suggest that different feed ingredients can alter the *Salmonella* status of pigs. Hansen *et al.* (2001) reported that offering finisher pigs heat-treated sugar beet pellets as opposed to wheat-based pellets reduced *Salmonella* sero-prevalence by 42%. In addition, Jorgensen *et al.* (2001) found that replacement of 25% of wheat by barley lowered *Salmonella* prevalence. The inclusion of barley results in more firmer intestinal contents which are retained longer within the stomach where the acidic conditions can prevent *Salmonella* DNA replication. There is limited research on the effect of feed ingredients on the *Salmonella* status in pigs and it is therefore difficult to assess the effectiveness of this control measure.

Feed particle size – It has been suggested that increased particle size improves the microbial profile of the stomach by promoting Lactobacilli growth and inhibiting *Salmonella* replication (Dahl *et al*., 1999). Papenbrock *et al.* (2005) and Jorgensen *et al.* (1999) reported that coarsely ground pelleted feed reduced *Salmonella* prevalence by 60 and 49% respectively. However, Kjeldsen and Dahl (1999) did not observe any significant difference in *Salmonella* status of pigs fed coarsely or finely ground feed. While it appears that coarse ground feed can be an effective control measure against *Salmonella*, the results are not always consistent.

Husbandry measures – A lack of farm hygiene has been reported to increase the prevalence of *Salmonella* (Berends *et al*., 1996). Mannion *et al.* (2007) conducted a study in Ireland to determine the efficacy of cleaning and disinfectant procedures used in commercial finisher units on Enterbacteriacae and *Salmonella* counts. These workers found that cleaning and disinfection was effective at reducing bacterial levels on pen floors. However, this study also highlighted the high level of contamination of feeders and drinkers within the pen after cleaning and disinfection. It was concluded that this contamination was a direct source of infection and the requirement for careful cleaning and disinfection was stressed. These workers suggested that in order to reduce this contamination, a disinfectant should be added to the wash water and the power washer pressure reduced as this reduces the generation of aerosols (Gibson *et al*., 1999). Despite the plethora of evidence outlining the benefits of cleaning and disinfection, there are some studies which have found that producers which do not use a disinfectant after pressure washing have a lower *Salmonella* prevalence on their herds (Van der Wolf *et al*., 2001). It is possible that producers that use disinfectant clean less thoroughly than those that do not, assuming that any remaining bacteria will be dealt with by the disinfectant. As Thomas (1982) found that disinfectants are inactivated by inorganic matter, this seems to be the most likely explanation for the disinfectant paradox.

All in/all out systems of production have been reported to be an effective control measure against *Salmonella* as this allows complete cleaning and disinfection as well an opportunity to empty the pit underneath the floor (Lo Fo Wong *et al*., 2004). However, in contrast, Proescholdt *et al.* (1999) found no significant difference between all in/all out and continuous flow systems in the United States.

Off-site weaning is another husbandry control measure with several researchers reporting a reduction in *Salmonella* prevalence (e.g. Nietfeld *et al*., 1998; Dahl *et al*., 1997. However, it is of the utmost importance that the pigs are transferred to clean facilities or this intervention will not be successful.

In Sweden, depopulation is used as a control measure and other countries have also seen some success with this method (e.g. Denmark, Dahl *et al*., 1999 and Mogelmose *et al*., 1999). Nevertheless, this intervention is not always successful as contamination can persist on some units and replacement pigs become infected. Wahlstrom *et al.* (1997) found that it was not possible to eliminate *Salmonella* on a particular unit without permanently decreasing the pig population by 50%.

In terms of husbandry control measures to control *Salmonella*, good biosecurity and hygiene, combined with all in/all out systems appear to be effective but they need to be operated properly to ensure success. The maintenance of a high herd health status and the absence of other infections (e.g. PRRSV, PMWS) can reduce *Salmonella* prevalence (DEFRA, 2006).

Vaccination – Friendship *et al.* (2009) reviewed 15 studies which evaluated the effectiveness of vaccination as a control measure for *Salmonella*. Of the 15 studies, 14 reported beneficial effects in terms of reduced *Salmonella* prevalence. For example, Roesler *et al.* (2004) observed a 20-80% reduction in the number of weaned pigs shedding *Salmonella* and Linder *et al.* (2001) observed over 86% reduction when sows were vaccinated. Live vaccines, orally administered have been shown to provide the best protection and should be considered as a control measure against *Salmonella*. However, the majority of studies evaluating the use of *Salmonella* vaccines are small-scale and it is necessary to perform more large-scale field trials before economic decisions can be taken (Wray, 2001). In addition, vaccinations are typically against one specific serovar of *Salmonella* and therefore are not protective against other serogroups (DEFRA, 2006).

Probiotics – In theory, the addition of probiotics to a diet should be an effective control measure for *Salmonella* as they promote Lactobacilli growth which alters the pH of the intestinal tract. Indeed, Baum and Harris (2000) reported that *Salmonella* shedding was reduced in pigs receiving Lactobacillus. However, there is very little other evidence to support these findings and they are in contrast to those reported by Letellier *et al.* (1999). This lack of evidence, combined with the long list of screening and selection procedures necessary to classify a probiotic (Friendship *et al*., 2009) mean that these products are unlikely to be an effective control measure against *Salmonella*.

Antimicrobials – Again, it would be expected that, in theory, antimicrobials should be an effective method of *Salmonella* control but a review of relevant studies has found

that they promote the selection for resistant serovars and can lead to a more severe infection of *Salmonella* (Friendship *et al.,* 2009).

Summary – There are several control measures described in the literature which have been reported to have varying degrees of effectiveness on-farm. It would appear that no single measure can be fully effective on its own but a combination of measures may provide better protection. An effective *Salmonella* control programme should include good biosecurity and husbandry practices, consideration of feed form, particle size and feed type. It would also be advantageous to further evaluate the use of vaccination.

Methods of detecting *Salmonella* on-farm

The ELISA test has been established as being useful in detecting the prevalence of *Salmonella* on-farm but is not able to identify individual pigs which are shedding *Salmonella* at the point of slaughter (Wray, 2001). EFSA (2008) states that the ELISA test is not useful for target setting as the serological status on-farm is a poor indicator of public health risk. However, EFSA (2008) also stated that the ELISA serological test is a valuable tool for on-farm *Salmonella* surveillance purposes. Despite being a poor predictor of individual pig *Salmonella* status (Davies *et al*., 1999), there is evidence to suggest that a pig, seropositive for *Salmonella* is twice as likely to yield a *Salmonella* infected carcass (EFSA, 2008). The main problem with the ELISA antibody test is that it does not give information about the current *Salmonella* status of the slaughter pigs coming from a particular farm – it only indicates whether or not pigs have been exposed to *Salmonella* at some stage of the production cycle. A bacteriological test on faeces from individual pigs leaving the farm would be the definitive measurement of the on-farm status of individual pigs. Currently testing of individual pigs is impractical due to the time and labour required to sample and the prohibitive cost of analysis. This may be circumvented by collecting pen samples (multiple faecal samples from a pen of animals) a few days prior to transport and evaluating recently developed rapid sensitive DNA based *Salmonella* detection methodologies that have the capability to quantify bacterial load. It is believed that this combined approach of composite sampling and DNA based analysis may provide a viable inexpensive, quantitative procedure in the near future. However, it is important to remember that stress can increase *Salmonella* shedding and therefore a pig which is serological positive but bacteriological negative on leaving the farm may begin to shed *Salmonella* due to the stress of transport and lairage and thus potentially result in a *Salmonella* positive carcass. Therefore, if seroprevalence can be reduced on-farm, this would in turn ultimately lead to a reduction of *Salmonella* within the factory.

As outlined in the section above there are a number of biosecurity, husbandry and nutritional methods to reduce *Salmonella* prevalence but in order for interventions to be effective they must be targeted to the point of infection. The problem for NI pig producers is that the point of infection is unknown. There have been a number of "longitudinal" studies conducted in other European countries which utilised the ELISA test to identify the main point of infection (Merialdi *et al*., 2008; Kranker *et al*., 2003; Lo Fo Wong, 2004). Lo Fo Wong (2004) showed that there was a positive correlation between the proportion of growers which were seropositive and the number of finishers that were ultimately seropositive. This would suggest that testing

of growing pigs may be a means of identification of finishers which potentially could be a *Salmonella* risk within the factory. However, as stated, the point of infection within NI farms is not known and a longitudinal study should be conducted to establish this. When this is known, intervention measures can be targeted and on-farm reduction of *Salmonella* should be achieved.

Recommendations for on-farm research

- To identify the point of infection on NI farms through scientific longitudinal studies on representative farms. This will be achieved through the use of ELISA testing of blood samples from sows and pigs from weaning to slaughter and through bacteriological testing of faecal samples.
- To identify factors which contribute to *Salmonella* prevalence on-farm. The literature indicates that these factors can be identified through the use of a comprehensive producer questionnaire and listed in order of priority through the development of a statistical model.
- To develop and validate targeted on-farm control strategies to reduce *Salmonella* prevalence. The strategies will be focussed on the point of infection identified from the longitudinal studies and on modifying management practices which influence *Salmonella* infection identified through the questionnaire.

Transport, lairage and factory

The Slaughterhouse hygiene risk assessment tool

The Food Standards Agency has developed an on-line hygiene tool for use by processors to measure pathogen control efficiency throughout processing (Howell and Hutchison, 2009). It was concluded that the hygiene tool would be useful in identifying processes which could be modified to reduce *Salmonella* in the processing factory. The hygiene tool is available for use online at www.ukmeat.org and the scientific justification for the tool is summarised below. Information that relates to specific questions is highlighted with the appropriate question number in brackets.

Pig Transport and Lairage

An extensive *Salmonella*-based genotyping study in a Portuguese abattoir (Viera-Pinto *et al*., 2006) concluded that there were three main ways that *Salmonella* could be spread between populations of pigs. These ways were on-farm spread (see above, Q1-Q18), spread during transport (Q19-Q23) and spread during lairage (Q24-Q31). It has been found that the majority of cross-contamination events were confined to the lairage, nevertheless it is important to consider the influence of transport on *Salmonella* contamination. The importance of clean pigs at slaughter has been shown to be a risk indicator of the likelihood of *Salmonella* contamination of carcasses (Letellier *et al*., 2009). Indeed, Berends *et al.* (1996) commented that 70% of pig carcass contamination is from the slaughtered animal itself with the remaining 30% being acquired from other pigs (i.e. cross-contamination from contaminated pigs Q19). The link between the presence of *Salmonella* in caecal content and contamination of the finished carcass with the organism has been well established

(McDowell *et al*., 2007), as in a cross sectional survey across four abattoirs a significant correlation was seen between the presence of *Salmonella* in caecal content and presence on carcass swabs. Most often *Salmonella* infected pigs on-farm are subclinical carriers of *Salmonella*, displaying no obvious clinical symptoms and only intermittently excrete *Salmonella* bacteria in their faeces. However, during transport it has been observed that the prevalence of shedding from these carrier pigs will increase (Davies *et al*., 1999, Berends *et al*., 1996, Hurd *et al*., 2002) posing a risk of cross contamination to other pigs. Several other researchers have also reported a significant increase in the number of pigs excreting *Salmonella* upon arrival at the slaughterhouse (Williams and Newell, 1970; Berends *et al*., 1996; Rajkowski *et al*., 1998). The reason for this increased shedding has not been entirely revealed but is thought to be due to increased stress through mixing and transport.

The differences in the prevalence of *Salmonella* enterica between pigs on farm and at the abattoir suggest that either the transport process (Q19-Q23) and/or the abattoir-holding pens (Q24-31) pose significant *Salmonella* enterica risk to swine immediately pre-slaughter (Berends *et al*., 1996; Hurd *et al*., 2002; Hurd *et al*., 2001; McKinley *et al*., 1980). This risk of *Salmonella* cross-contamination is further heightened by the likelihood of carry over from previous batches of pigs, as while lorries may be cleaned between journeys it is reported that this cleaning does not remove all of the *Salmonella* from a contaminated vehicle (e.g. Mannion *et al*., 2008, Rajkowski *et al*., 1998). Indeed, previous work has shown that in the UK, effective cleaning and disinfection is not universal. Whilst transport lorries may be routinely hosed down, it is commonly found that they are not effectively decontaminated using chemical disinfectants. Effective cleaning and disinfectant of the transport lorry is an important control measure to reduce *Salmonella* cross-contamination. In addition, some recent work involving phage therapy with a microencapsulated anti-*Salmonella* phage cocktail administered prior to transport has been shown to have potential to reduce cross-contamination during transport and in lairage (Wall *et al*., 2010). It would be of interest to investigate this further.

As already stated, lairage is a high risk area for *Salmonella* cross-contamination and it has been suggested that increasing the holding time in lairage will increase this risk (EFSA, 2010). However, other published experimental evidence is somewhat contradictory on the effect of lairage holding time (Craven and Hurst, 1982, Morgan *et al*., 1987; Beloeil *et al*., 2004). As a consequence of the conflicting findings, the relative weightings applied to time in lairage are low within the hygiene tool (Q24).

The type of flooring in lairage (concrete slats vs. solid ridged concrete; Q26) has been identified as a factor associated with the amount of *Salmonella* contamination. Hurd *et al.* (2005) found that the proportion of *Salmonella* enterica-positive samples was highest ($P<0.05$) in the caecum of pigs on solid concrete floors (72.4%; Q26), and slightly less for pigs on slatted floors (63.3%; Q26). Animals held for less than 45 min before slaughter demonstrated the lowest proportion of *Salmonella* enterica-positive samples (52.9%; Q24). However, meat quality, as measured by multiple parameters (pH, colour and drip loss), was adversely affected by the lack of a rest period after transport and lairage is thus viewed as necessary from a meat quality perspective (Hurd *et al*., 2005).

Rostagno *et al.* (2005) demonstrated that resting pigs prior to slaughter on their transport vehicle (Q25) had the potential to reduce the prevalence of *Salmonella* enterica-positive pigs at slaughter. A prerequisite however for such an intervention is that the lorries are effectively cleaned and disinfected between different batches of pigs (Rostagno *et al*., 2005; Q19-23).

The study of Schmidt *et al.* (2004) investigating cleaning and disinfection procedures using both a detergent and disinfectant in pig lairage pens at a large US-Midwest abattoir clearly showed that cleaning and disinfection effectively reduces the amount of culturable *Salmonella* enterica in the lairage pen environment, which would intuitively lead to a reduced prevalence of *S. enterica* on pig carcasses (Q27-Q29). A similar conclusion was derived from a Belgium study (Delhalle *et al*., 2008). However, within the hygiene tool, the weighting applied for Q27-Q29 is quite low because of a lack of a significant difference in the isolation of *Salmonella* from internal organs (Schmidt *et al*., 2004).

A sevenfold-higher *S. enterica* isolation rate from pigs slaughtered at abattoir (39.9%) after transport and holding than from those slaughtered on farm (5.3%) was demonstrated by Hurd *et al.* (2002). The recovery of additional serovars at the abattoir is strongly indicative that the pigs were infected after leaving the farm. The study demonstrated that rapid infection during transport, and particularly during holding, could potentially be a major reason for increased *Salmonella* enterica prevalence in pigs. Holding pens have been identified as an important *Salmonella* enterica control point in the pork production chain (Q19-23 27-29). This was supported by the study of Larsen *et al.* (2004) in which *Salmonella* enterica was isolated from 44% of the no-hold sows at abattoir, which was significantly less than 59% (47 of 80) of the held sows. The *Salmonella* enterica serovars isolated from no-hold sows were generally different from those isolated from held sows. In a separate, earlier study, the prevalence of *Salmonella* enterica in cull sows at various stages from the farm to the abattoir (Larsen *et al*., 2003) was investigated. Faecal samples from cull sows on the farm and at the live market were 3% and 2%, respectively. After transport from the market (10 h) and holding at the abattoir (6 h), 41% of cull sows yielded *Salmonella* enterica in one or more sampled tissues. In addition while two *Salmonella* enterica serotypes, Derby and Infantis, were found on the farm and at the market, 12 serotypes that had not previously been found on the farm or at the market were recovered at the abattoir. The market holding pens had wood shavings on the floors which may have reduced the level of moisture and led to a reduction in the incidence of *Salmonella* enterica and diversity of serotypes than would have been expected. Consequently, the use of dry fresh bedding may be a useful pen-level intervention (Q26). As with the previous studies, the results of Larsen *et al.* (2003) demonstrate that transport (Q19-Q23) and holding practices (Q24-Q31) contribute to an increase in *Salmonella* enterica infections in pigs prior to slaughter.

An Irish study, (Bolton *et al*., 2002) found that the power-washing of pigs on exit from the lairage reduced contamination by *Salmonella* from the 27% measured on farm to only 10% (Bolton *et al*., 2002; Q31). However, power-washing of pigs may constitute a welfare issue and it differs from the 'spray washing' of pigs commonly practiced in lairages in the UK. FSA project MO1038 found pre-washing carcasses before scalding kept the scald tank water visibly cleaner (Q31) as did an earlier study (Wal and Mulder 1996; Q18, Q31). Spray washing involves the pigs being bathed in

a fine mist of water, which serves to calm and cool them alongside any concomitant improvement in the cleanliness of the animal. In an analysis of risk factors for the prevalence of *Salmonella* in the 10 largest pig slaughterhouses in Belgium, omission of spray washing of pigs in the lairage was shown to be positively associated with increased bacterial contamination (Delhalle *et al*., 2008). Therefore, low pressure spray washing may also be viewed as beneficial in reducing *Salmonella* contamination of the carcasses and a systematic procedure using sensor-activated spraying of the pigs at temperatures >15^{o}C has been recommended (Monin, 2003) (Q30).

A mathematical modelling study has identified the lairage as the most cost effective position within the pork production chain at which to focus interventions against *Salmonella* contamination (Van der Gaag *et al*., 2004). However, this is with the caveat that if operating procedures further down the production chain (at slaughter) were not also improved the improvement in the lairage was largely cancelled out. In summary, the time held in lairage, cleaning and disinfection of the lairage and the use of fresh clean bedding are all factors which can positively influence the infection and contamination status of pigs destined for slaughter.

The Slaughter Process

When pigs enter the slaughter process, the characteristics of interest changes from the infection status, to the proportion and load of contaminated carcasses and intestines (Berends *et al*., 1997; Botteldoorn *et al*., 2003). There are many studies that report the prevalence of carcass contamination during the slaughterhouse process (e.g. EFSA, 2008), however very few actually record the prevalence at the start of processing (i.e. immediately post-lairage). Within groups of slaughter pigs, there is a correlation between the proportion of animals carrying *Salmonella* in the faeces and the proportion of contaminated carcasses (Davies *et al*., 1999). The exterior of live pigs entering the slaughter process may be polluted with faeces or dirt containing *Salmonella*. If *Salmonella* is present on the exterior, the pig is said to be contaminated. If *Salmonella* is present in the intestines of the animal, the pig is said to be infected. Cross-contamination is the contamination of a carcass (or other unit under investigation) by means of a second agent (e.g. a cutting knife, or the scalding tank), which has previously been contaminated by another carcass. Cross contamination from the animal itself (evisceration), from the plant, machinery and workers are widely held as the principal sources of microbial contamination during processing (Gonzales Barron *et al*., 2009).

The slaughterhouse environment varies throughout the EU and within slaughter stages the specific equipment and settings of the machinery are also not constant. Within a slaughterhouse several stages may be distinguished and are summarised in Figure 1. Some of these stages may have little or no impact on *Salmonella c*ontamination while others are recognised as highly relevant.

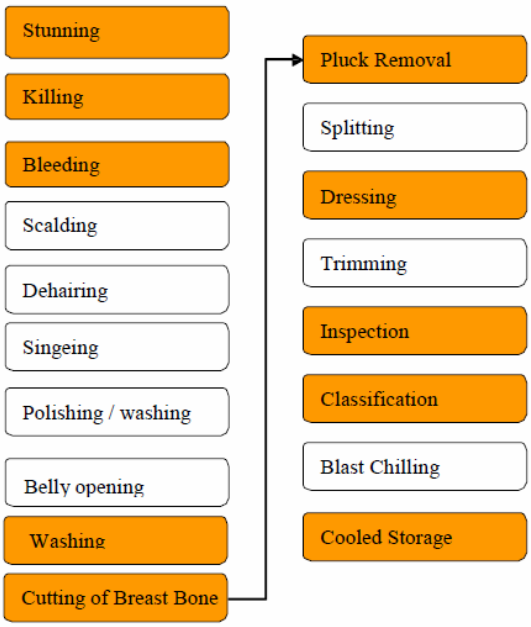

Figure 1: Stages of carcass processing

Pig stunning and bleeding

Pigs are stunned by means of either an electric shock or gas method (Q32). For the latter pigs are stunned using carbon dioxide. This treatment relaxes the muscles (as opposed to electrical stunning) and may lead to increased shedding of *Salmonella* through voiding of faeces. Furthermore, pigs have contact with each other and with the slaughter floor, potentially leading to cross-contamination. After stunning, the pigs are subsequently killed by severing the main artery in the neck ('sticking'). Also, methods are used where longer knives penetrate all the way through the heart. Finally, the pig bleeds for some time before entering the scalding bath. Carcass samples taken after the bleeding stage of processing indicated an increase in the contamination of carcasses by *Salmonella* from 10% to 50%. In both Irish and Indian studies of carcass swabs, numbers of total mesophilic aerobes have been shown to be at their highest immediately after exsanguination as stunned animals tend to fall onto the same section of floor and the floor is not cleaned between animals (Q33-Q36, Bolton *et al*., 2002, Gobat and Jemmi, 1990, Kadam *et al*., 2005, Pearce *et al*., 2004). Cross-contamination shortly after this stage of processing may be exacerbated by contact with a gambrelling table and, once shackled onto the line, initially being dragged across the table before hanging free from the line. A recent comprehensive analysis of microbiological surface test results from more than two thirds of UK pig plants found that a large number of plants had difficulties in effectively cleaning and sanitising sticking and gambrelling surfaces (Hutchison *et al*., 2007; Q33-Q35). Patterson (1969) and Schütz (1991) have both suggested *generally* that the area of the floor on to which the animal falls after stunning should be either slats or grating (Q31) and that this area should be kept as dry as possible to avoid carcass surface contamination and wetting.

Blood and internal tissues of pigs can be contaminated during sticking by unsanitary knives (Jensen and Hess, 1941; Troeger, 1994; Woltersdorf and Mintzlaff, 1996).

However, Troeger (1994) concluded that the risk was slight but the speed and efficiency of stunning and bleeding may also influence the contamination of pig carcasses. The more rapid and efficient these parts of the process are, the quicker the blood circulation will stop and thus potentially there will be less risk for the scald water entering the system, via the cut, to reach all the tissues. A suitable delay between bleeding and scalding of ≥5 minutes has been recommended (Richmond, 1991; Troeger, 1993; Q40). Outputs from FSA study MO1038 suggest that the presence of blood in the scald tank is associated with increased carcass contaminations.

Bell (1997) reported that contamination of knife blades was important as a source of contamination during the sticking of cattle. Knives were however less contaminated, by at least an order of magnitude, than the numbers of bacteria found on an operative's hands when blades were sanitised by immersion in water at 82°C. Similarly, Mackey and Derrick (1979) showed that the blood and internal tissues of lambs and cattle could be contaminated during sticking. As a consequence of these studies, sterilisation of knives used for bleeding has become a regulatory requirement in the UK. The use of clean knives at the sticking stage of processing is considered to be more important than subsequent stages because immediately after stunning, a functional circulatory system still exists in the animal, and there is evidence that, despite innate immunity, this system can convey bacteria into deep muscle tissue (Bell, 1997). There does not seem to be corresponding information specifically for pigs that the use of contaminated knives is a risk to carcass hygiene, but as before it is the contaminated instrument rather than the carcass type that is important as a fomite (potential vehicle of infectious pathogens in the environment) and thus Q37-Q40 are included in the hygiene tool (with a relatively low weighting to reflect a species-specific lack of evidence). With respect to knife sanitisation many current international regulations allow science based procedures to be used. A recent Australian study (Goulter *et al*., 2008) demonstrated dipping knives in water at 82°C for 5 seconds was as effective as 70°C for 45 seconds in achieving at least a 3 log reduction in microbial load. In addition, a 40°C pre-rinse increases the performance of the disinfection.

Scalding and dehairing

During the scalding phase, the pigs are submerged into the scalding bath, containing hot water. The primary objective is the loosening of hairs for removal in the following stage. From a microbiological quality point of view, the high temperature potentially reduces the pathogen levels on the exterior of the pig, and in addition, *Salmonella* may be washed off. Relevant parameters are the temperature of the scalding water, the number of pigs sharing the scalding bath and the time spent in the scalding bath. A potential risk is contamination of the scalding water, which could contaminate the skin of subsequent pigs that enter the scalding bath.

Dehairing takes place in the dehairing machine but in many cases, scalding and dehairing are combined in a single machine. Dehairing equipment consists of a rotating drum with extensions (e.g. brushes or flaps) at the inside. This procedure removes the bulk of the hair. However, due to the vigorous action of this machine, some faecal material will be voided, potentially contaminating both the pig and the machine. Plugging the anus to prevent the escape of faeces into scalding water, or during dehairing, scraping or polishing, has been recommended in a number of reports

(Richmond, 1991; ICMSF, 1998; Wong *et al*., 2002; Purnell *et al*., 2010; Q42- Q51). Bolton *et al.* (2002) suggested that the level of contamination at dehairing might be reduced if a plastic cone was applied to the anus to reduce the opportunity for faecal contamination from that region (Bolton *et al*., 2002).

In some processing plants, there is a pre-scald stage and commercial whipping and brushing machines similar to those used for post-singe scraping and polishing are marketed by a number of equipment manufacturers worldwide for this stage (Tinker *et al*., 2007; Woltersdorf and Mintzlaff, 1996; Rahkio *et al*., 1992). An alternative pre-scald treatment is hot water washing, also used for pre and post-evisceration carcass treatment (Gill *et al*., 1997; Gill and Jones, 1998; Kotula, 1987; Namvar and Warriner, 2005). FSA project M01038 indicates that pre-scald washing of pig carcasses with hot water prior to scalding and dehairing has a small beneficial effect on surface *Enterobacteriaceae* numbers on pork carcasses prior to evisceration. Thus, pre-scald washing may be seen to have some benefit (Q43).

After effective scalding, pig carcasses have rarely been shown to be contaminated with readily detectable quantities of human pathogens (Berends *et al*., 1997; Bryant *et al*., 2003) with scalding responsible for a 4 log reduction of the levels of total aerobes and coliforms (Dehalle *et al.,* 2008; Pearce *et al.,* 2004; Spescha *et al*., 2006). However, effective scalding is dependent on a number of factors including temperature, duration and renewal of water. Scalding temperatures of 61±1°C for 8 min (Pearce *et al.,* 2004) or 54 or 60°C for 9 or 7 min (Dockerty *et al*., 1970) significantly reduced the incidence of *Salmonella* on carcasses and hence it is considered as an important control measure (Q45-46; Q52-Q56). Wilken *et al.* (2007) recommended that the temperature of the scalding water should range between 58°C and 64°C, with an average of 60°C. It has been found that renewal of water during scalding has a dramatic impact on organic load and subsequent *Salmonella* prevalence after scalding (Smulders and van Laack, 1992). An alternative to vat scalding is spray scalding, where the pig is not immersed in hot water, but rather a hot spray is applied. There are little data on the frequency of this scalding method and the effect of spray scalding on contamination levels (Troeger, 1993). However, scalding using condensed water vapour has been shown to offer a number of advantages, in terms of bacterial numbers reductions, over conventional tank scalding (Nickels *et al.,* 1976; Nerbrink and Borch, 1989; Woltersdorf and Mintzlaff, 1996; Q44). Correlation between the operation of such condensed vapour scalding systems and a reduction in *Salmonella* prevalence and counts of *Escherichia coli* and aerobic bacteria on the finished carcass has been documented (Delhalle *et al*., 2008).

A consistent theme across publications that have investigated scalding is that it is effective at reducing bacterial numbers and the incidence of detection of potential human pathogens such as *Salmonella*. However, after scalding, carcass surfaces have been shown to become re-contaminated with bacteria mainly as a consequence of dehairing and subsequent stages of processing (Bryant *et al*., 2003; Pearce *et al*., 2004), however APC are still significantly lower than those measured on the same carcasses after bleeding. A number of authors have reported similar observations and it is now well established that numbers of bacteria follow trends similar to that depicted in Figure 2 for the *Enterobacteriaceae* during each of the different processing stages.

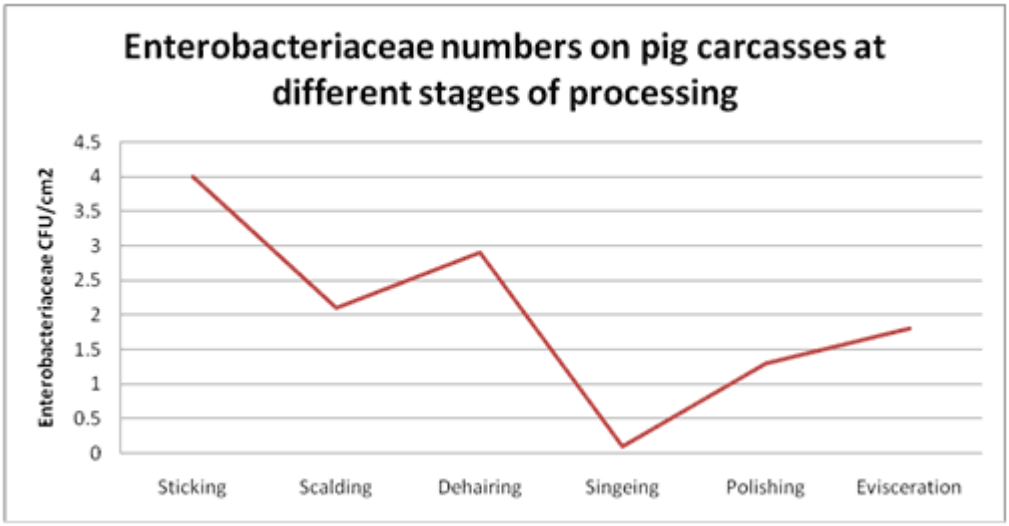

Figure 2: *Enterobacteriaceae* isolated from pig carcasses by swabbing at each stage of processing (Berends *et al*., 1997; Bolton *et al*., 2002; Pearce *et al*., 2004).

While one study found no direct connection between bacterial numbers in tank scalding water and the hygienic status of carcasses that have passed through the water (Troeger, 1994) a survey of abattoirs across Europe, (Hald *et al*., 2003) found that *Salmonella* contamination during pluck removal was related to the effectiveness of scalding and reported that *Salmonella* in the scald water increased the likelihood of isolating *Salmonella* from the carcass after evisceration (Q46). Furthermore, Letellier *et al.* (2009) determined, from analyses of pigs from 312 production lots, that the presence of *Salmonella* in the scald tank water was a significant risk factor which correlated with *Salmonella* contaminations of the final carcasses (Q46; Q48; Q50). Effective scalding is therefore essential to reduce the prevalence of *Salmonella* throughout the processing line.

Namvar and Warriner (2006) studied dehairing by scraping, where pigs are laid on the horizontal between a pair of flanged rubber rollers which are then rotated, rotating the carcass and stripping the hair from its surface. Based on the movements of generic *E. coli*, the study concluded that in terms of cross contamination, the scraping stage was the second most important cause for carcass-to-carcass contamination (Q57-Q59). It should be kept in mind that samples were not taken after all of the processing stages and that there are some fundamental differences between scraping and flail dehairing.

Singeing and polishing

The singeing stage aims to remove any remaining hairs left after the dehairing phase. The pigs are subjected to very high temperatures (approximately 800-1000ºC) in a singeing machine, where remaining hairs are burnt. As a side effect, it also burns or dries dirt and faecal material. Typically, a singeing machine consists of two heated half shells closing on the pig, or a heated tunnel. Singeing is considered to be the most effective stage for microbial inactivation. Its efficiency is dependent on the time spent in the machine and the temperature to which the pig is subjected. Note that it is possible to have dehairing and singeing combined in one single machine.

The polishing machine, also known as the 'wet scraper', is a tunnel with a car-wash like series of brushes with flaps. Almost all dried dirt and other contamination (e.g. debris of hairs after singeing) is removed or loosened during this phase. Similar to the dehairing phase, there is a risk of cross-contamination at this step and some faecal extrusion may take place. Note that the polishing stage is not implemented in all countries. Sometimes the polishing phase is replaced by a manual washing step (Bolton *et al*., 2002).

Effective singeing can result in almost complete removal of skin-surface contamination (Bolton *et al*., 2002; Pearce *et al*., 2004). Recent work, sponsored by the UK Food Standards Agency, has determined that singeing flames may not always uniformly heat the surface of pig carcasses (Q67). Although singeing is undertaken to help facilitate removal of hair, an advantage of effective singeing is that it also helps reduce bacterial numbers on the carcass surface. Some designs allow areas of the carcass to stay below 50°C which has been shown to be too low to cause bacterial death. Thermal imaging can be used to reveal the temperature profile of a carcass (Figure 3).

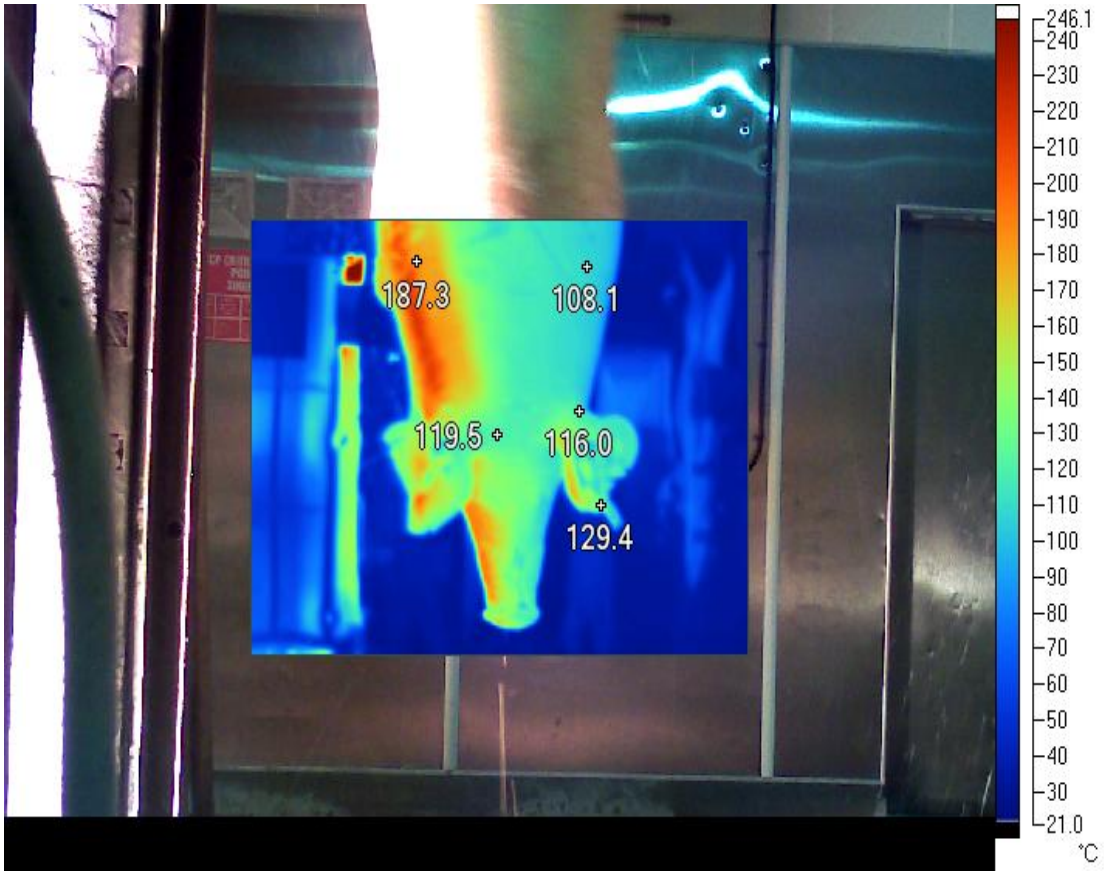

Figure 3: An example of a newly-singed pig carcass that shows the high temperatures that can be achieved by sarcophagus-style singeing equipment

However, if singeing is not effective, the polishing stage that routinely occurs after singeing, has been estimated to be directly responsible for between 5% and 15% of all

carcass cross-contamination on pork lines by redistributing those few bacteria that survive the flame treatment across the surface of the carcass (Berends *et al*., 1997). In a small study from the USA (Yu *et al*., 1999) it was reported that a second singeing and second polishing stage reduced the numbers of total aerobes to their pre-singe numbers (Q61), providing evidence that duplicating the singe and polish stages of pig processing (Q65) may be a good microbiological practice.

Several countries in the European community have installed a second singeing apparatus with the aim of improving the hygiene of the finished product. The Agence Française de Sécurité Sanitaire des Aliments recommends double singeing as one of the mechanisms through which the level of pathogens on finished pig carcasses may be reduced (Kooh, 2007). One published study has made a comparison of the hygienic effect of single and dual singeing systems at three slaughterhouses in France (Minvielle *et al*., 2005). A reduction in total aerobic contamination over 2 log greater than that attained with a single singe and similar reductions in Enterobacteriaceae numbers were demonstrated.

Spescha *et al.* (2006) report information on the changes in numbers of total aerobes individually at the ham, back, belly and jowl of pig carcasses from 2 plants. Singeing was particularly and significantly effective at removing total aerobes from the belly of the carcass. In contrast to other reports, polishing increased the numbers of total aerobes on the carcass at plant A, but reduced it at plant B. Whilst there are some general points that can be made when reviewing the literature associated with meat processing, these results underscore the importance for adequate consideration to be given to the significant differences between individual plant's processes.

The exact mechanism of increasing bacterial numbers observed by a number of authors during the polishing of pig carcasses has yet to be satisfactorily explained. Yu *et al.* (1999) believe that most of the contamination comes from contaminated polishing equipment because there was an increase in carcass contamination correlated with the number of hours of processing (Q62-64). A recent publication that discussed trends in bacterial numbers on UK slaughterhouse environmental surfaces (Hutchison *et al*., 2007) found that polishing equipment is hard to clean and decontaminate effectively - the mean log numbers of total aerobes was 4.4 log CFU cm^{-2} on the carcass polishers after cleaning and sanitation and before the commencement of processing and that this may contribute to the elevated counts observed after polishing. Although Namvar and Warriner (2006) noted that a single genotype of indigenous *E. coli* was isolated from polishing equipment on each of two occasions they visited a plant, they believed that the *E. coli* was not persistent on the polisher and that it was freshly carried in from the lairage each day of production. Gerats (1990) reported that 20% of samples collected from a polisher during processing will be positive for *Salmonella* after enrichment and in another study (Van der Palen (1992) (*cited* by Berends, 1997) the proportion of positive samples obtained from the polishing equipment correlates poorly with individual carcass contamination suggesting cross-contamination from other carcasses. Palumbo *et al.* (1999) found that as the day progressed in one abattoir, carcasses passing through a final washer/polisher became increasingly contaminated supporting the need for regular cleansing of polisher equipment throughout the shift.

A second singeing after polishing has been demonstrated in a number of Belgian plants to significantly decrease carcass ACC (aerobic colony counts) and by inference *Salmonella* (Delhalle *et al*., 2008; 2009).

Evisceration of pig carcasses

Pre-evisceration power washing is an optional processing stage that is used to remove burnt/singed material missed or re-distributed by polishing. However, there is evidence that washing at this stage can lead to increased numbers of bacteria (Bolton *et al.,* 2002; Q72). On the other hand, Dockerty *et al.* (1970) found that pre-evisceration washing of pig carcass with clean water diminished the surface load and Miller *et al*. (1994) also reported small (<1 log), but significant reductions on pig carcasses following a pre-evisceration wash. There appears to be a lack of information in the published literature regarding the microbiological implications of pre-evisceration washing, although it is clear the practice has a potential to distribute bacteria on carcasses especially when the wash water is cool. The relatively low weighting applied to Q72 within the hygiene tool is a consequence of this uncertainty. Hot water washing (Q81) of pre-evisceration carcasses using 85°C for 20 s reduces total numbers of bacteria by around 2 logs (Gill *et al*., 1995; 1997). However, there are some meat quality concerns with this practice as detailed work on pre- and post-rigor pork and beef showed that while pre-rigor beef will recover to a certain extent from heat damage, pre- and post-rigor pork will not (Gill and Badoni, 1997). It was found that this treatment bleached the exposed muscle along the edges of the cut lines (Gill and Jones, 1998).

During evisceration, the belly is opened by a machine, using a small hook. Here the infection of the gut becomes relevant, since there is a risk of puncturing the colon, or rupturing the stomach, thereby re-contaminating the carcass or the hook. In between the processing of consecutive pigs the hook is "sterilised" inside the machine, i.e. washed with water at 82°C. After processing of a pig, the cutting hook is retracted into the machine and autosterilised using hot water treatment. The temperature of the water should be 82°C by EU regulation (Eustache *et al*., 2007). In Maribo *et al.* (1998) a sterilising time of 8 seconds is reported as sufficient for elimination of all *Salmonella* on the knife. However, this does not take into account the possible formation of biofilm, or recontamination of the knife after sterilising, by dripping of condensed water (Peel and Simmons, 1978). After belly opening, the gut (colon, small intestine, stomach, spleen) is loosened manually and put in a container. The main hazard is the spilling of faecal material and/or additional puncturing during manual loosening. Evisceration has been assessed as contributing to 55-90% of microbiological carcass contamination even if the gut contents are not ruptured during removal (Berends *et al*., 1997). Yu *et al.* (1999) also note that evisceration, even when it proceeds without rupture of the gut, increases carcass contamination generally (pre-evisceration wash was not part of either of these studies). However, in a low throughput slaughterhouse, the aerobic plate count after evisceration was not significantly different from APCs after pre-evisceration carcass washing or further inspection (Bolton *et al*., 2002; Warriner *et al*., 2002; Nerbrink and Borch, 1989). Worker attitudes are thought to have a significant impact as in Bolton *et al.* (2002), a single well-trained operative working at his own pace performed the procedure effectively while Berends *et al*. (1997) commented negatively on general worker hygiene at the evisceration stage with strong inference that workers were acting as fomites for subsequent carcasses (Q73).

There is an obvious hazard at the evisceration stage if the gut wall becomes punctured before the GI tract is removed. There seems however scant evidence that the removal of the digestive tract from pigs causes significant increases in carcass contamination unless the faecal material is spilled during the procedure. The small number of reports of increasing microbial load as a consequence of the evisceration process stage appears more likely to be fomite-mediated rather than a direct consequence of GI tract removal. This stance is supported by recent studies in Belgium (Delhalle *et al.*, 2009).

Tying followed by bagging (or otherwise sealing) the rectum after it has been cut loose has been shown to reduce the spread of faecally-derived contamination across pig carcasses (Q71). The effectiveness of the procedure has been reviewed previously (Sheridan, 1998). Other technical methods for sealing the rectum include the insertion of a frozen stainless steel plug into the anus before the rectum is excised. The plug either expands or forms an ice layer as it is warmed by residual heat in the carcass and forms a tight seal which resists the spread of faecal contamination (Anon, 1989). Christensen and Sørensen (1991) found that covering the heads of carcasses with bags and sealing the rectum with a tight-fitting plug reduced the numbers of *Enterobacteriaceae* on pig carcasses.

To counter anticipated problems of cross-contamination during head removal Bryant *et al.* (2003) modified operations at a small abattoir so that the head was removed and the carcasses hot water pasteurised prior to evisceration. When carcasses were pasteurised after head removal, the numbers of total aerobes on dressed carcasses were reduced by about 1 order and the numbers of coliforms and *E. coli* were reduced by more than 2 orders of magnitude.

The 'pluck' is a term encompassing the tongue, pharynx (including tonsils), oesophagus, trachea, heart, lung and liver. The pluck is removed manually, after which the pluck is put in a container. This phase probably has some risk as the pharynx, tonsil and tongue are very often heavily infected, as pigs during lairage tend to investigate their surroundings orally. Furthermore, during scalding the contaminated water can get into the lungs, and when the pluck is removed it can splash over the carcass, thereby potentially contaminating it. Therefore, care is needed at this stage to reduce contamination.

Many authors have concluded that cold water washing post evisceration does not decontaminate carcasses and serves to redistribute microbiota with the possible exception for samples collected from the belly (Bolton *et al.*, 2002). Individual sampling at the jowl, back, belly and ham suggested that post-evisceration washing caused a more even distribution of total aerobes across the four sampling sites (Spescha *et al.*, 2006). Increases in aerobic plate count after washing may be due to mobilisation of hitherto surface-bound bacteria (Bolton *et al.*, 2002; Q80). For decontamination a hot water wash at temperatures of 85°C or higher may be required (Gill *et al.*, 1995; Q81).

Line speed may have an important role in reducing the risk of cross contamination. It is acknowledged that faster line speeds provide more opportunities for mistakes to be made (Q82; Roberts, 1980) and that fast line speeds may have serious implications for

carcass hygiene generally (Sheridan, 1998). Although intuitively it seems obvious that this should be the case, there is evidence which both supports, and contradicts this hypothesis. Data from New Zealand abattoirs showed that increasing line speed increased bacterial numbers on carcasses (Bell, 1997). However, a US study reported that increasing line speed was correlated with decreasing numbers (Hogue *et al*., 1993 cited by Sheridan 1998).

Nevertheless, it is almost certain that decreasing the amount of time between carcasses (i.e. increasing line speed) will eventually begin to negatively impact on the effectiveness of sterilisation of knives, saws, bolts and other equipment that may be routinely sanitised by heat or steam between carcasses. Questions relating to line speed are included in response to the strongly-worded request from a panel of 20 academics who reviewed the slaughterhouse assessment tool. Furthermore a strong positive correlation between line speed and *Salmonella* contamination of carcasses specifically in pork plants has been recently reported (Letellier *et al*., 2009; Q82).

Carcass splitting

During the splitting phase, the carcass is split in two, top down by machine-saw, stopping at the neck. Between carcasses the saw is cleansed inside the machine. However, the inside of the machine is unreachable and therefore hard to clean and the saw might therefore be contaminated. This step is also risky because of *Salmonella* present in the oral cavity. After splitting, the carcass is dressed and during this phase, the kidney plus surrounding fat is removed which is mostly done manually. Like the pluck-removal phase, a negligible risk of cross contamination is assumed during this step.

In a multi-country European-based study investigating the sources of contamination in twelve pig plants, 9.4% of samples collected from carcass splitting equipment were contaminated with *Salmonella* (Hald *et al*., 2003; Q83-Q87). Contamination appeared to be associated at the individual plant level as a number of plants had no *Salmonella* and the range of positive isolations stretched from 5.6% to 31.1%. The band saw used for splitting the carcass before the samples were taken was also shown to acquire significant levels of *Enterobacteriacae* and *E. coli* during the processing shift (Warriner *et al*., 2002; Botteldoorn *et al*., 2003; Nesbakken *et al*., 2003; Q83-Q87). Bertrand *et al.* (2010) highlighted the risk of contamination during splitting as the splitting machine was clearly identified as the source of the 2005 outbreak of *Salmonella Ohio* in Belgium. A control measure to reduce the risk of contamination at this stage has been suggested by Delhalle *et al*. (2008). These workers found that complete washing and disinfection of the splitting blade three times per day, ensuring that the blade did not come into contact with the throat reduced the prevalence of *Salmonella* (2.05±1.05) and counts of *Escherichia coli* (0.89±0.37 log CFU cm^{-2}) and total aerobic contamination (0.76±0.26 log CFU cm^{-2}) in one slaughterhouse (Q83-Q87).

Decapitation of pig carcasses

In most pig processing operations, it is common procedure to keep the pigs' heads on until after cooling. However, the head is associated with high levels of microbial contamination (Q88-89). The prevalence of *Salmonella* was shown to be higher in the tonsils and tongues, than carcass, liver, and lymph node (Swanenburg *et al*., 2001a; b). Furthermore, the percentage of *Salmonella*-positive samples collected in several

European abattoirs was higher from tongue samples (7.9%) than carcass (3.8%) or liver (5.5%) (Hald *et al*., 2003). In addition, Morgan *et al.* (1987) reported that the cheek surface of pig carcasses prior to chilling was the most frequently contaminated area with *Salmonella* (18% of the samples) and high APCs, a consequence of this area being the drain point for washings from the entire carcass. Therefore, processing associated with the head are of particular concern and early head removal or head removal immediately before decontaminating intervention (even before evisceration) is considered to be a beneficial practice including excision of the tongue and tonsils, post-mortem meat inspection of the head, including the incision of the mandibular lymph nodes, and final removal (Nottingham, 1982; De Zutter, 1996; Fredriksson-Ahomaa *et al*., 2000; 2001; Q89). Wong *et al.* (2002) suggested that contamination from the oral cavity would be largely avoided if the head were removed from the carcass before the soft palate is breached and that the un-split head from pigs from high-risk herds were removed early in the process.

Inspection of pig carcasses

Carcasses are inspected for visible contamination, which if found is removed by manual trimming by slaughterhouse personnel with a knife which is sterilised in-between actions. Care is taken to remove a large portion around the contamination, not touching any of the contamination. In the case of visible faecal contamination of pork carcasses a steam-vacuum system should be considered by the meat industry as a good alternative to traditional knife trimming (Delhalle *et al*., 2009). Steam vacuuming, that delivers hot water, typically at >82°C, plus steam directly to the carcass surface and simultaneously physically removes the mixture of contamination and water through a vacuum, has been developed and trialled in the USA, UK and France as an alternative to traditional knife trimming, but only in France has its effectiveness been assessed on pig carcasses (Le Roux *et al*., 2008). Although the observation that steam vacuum treatment produced a reduction in total aerobic counts on the rind that was significantly superior than knife trimming, on meat there was no significant difference in the reduction of bacterial numbers seen between steam vacuuming and knife trimming.

Meat inspectors examine the carcass, intestines and pluck, to see if the carcass contains any risk for human health when consumed. This includes looking for indicators for disease or infection (Mousing *et al*., 1997). Inspectors handle the carcass manually, make incisions and perform palpations. The inspector uses his hands and also knives for making incisions in lymph nodes (Pointon *et al*., 2000). If visible contamination is identified (e.g. abscesses, swellings etc.) the carcass is diverted to a separate line and the offending deviation is removed. Tonsils, associated with high numbers of zoonotic agents, are required to be removed with care and meticulous GHP or the practice is potentially hazardous (Bülte *et al*., 1992; Leps 2007; Q91). Other practices carried out by meat inspectors (either plant or official) are potential hygiene risks (Berends *et al*., 1996; Borch *et al*., 1996; Skovgaard, 1996; Q96). However, it is assumed that hygiene is high at this inspection stage and that the risk is low. Nevertheless, the finding that *Salmonella* species can be isolated from the ileum of pigs indicates that care is needed at this stage (Viera-Pinto *et al*., 2006). A very likely way for zoonotic agents to inhabit this niche is by the ingestion of faeces which promotes tonsil infections (Q30) and internal dissemination of zoonotic agents through the mandibular and ileocolic lymph nodes. Carcass contamination by such a route may well be increased by imperfect evisceration and by hygienically

inappropriate meat inspection procedures, especially those requiring mandibular lymph node incisions.

Bacteriology

In the UK, microbiological testing of carcasses is undertaken largely for statutory or retailer compliance and as such has been incorporated into the hygiene assessment tools for pigs. The inclusion of microbiological testing was largely because they are now an established practice in most UK meat processing plants and because the statutory tests are undertaken according to standardised sampling and testing protocols. However, it is important to note that there is no science-based evidence which supports significant benefit in terms of process control when using microbiological testing and the sample numbers stipulated by the regulations. Indicator bacteria are distributed normally across the surfaces of carcasses (areas of the carcass surface just a few mm apart) can have up to 1 million times difference in the bacterial numbers recovered from them. Consequently, the wide range of numbers encountered across the surface of a carcass means it is difficult to justify how accurately the test results reflect operating conditions (Hutchison *et al*., 2007). In recognition of this shortcoming, the bacteriology section of the Slaughterhouse Risk Assessment Tool compares the total aerobic count and *Enterobacteriaceae* test results generated in an individual plant, over a period of up to one year with the test results from all of the other UK plants which process the same species. It is believed that grouping multiple test data in this manner provides a more balanced overview of long term operating conditions in plants. Improvements in processing hygiene in UK meat plants between 2002 and 2006 have been demonstrated using the UK national meat test results dataset (Hutchison *et al*., 2007).

Swab sampling has been shown to be effective in determining the prevalence of *Salmonella* (Ghafir and Daube, 2008) and *Salmonella* testing of carcass-derived samples is undertaken in the UK for process control purposes (which is different to food safety purposes). If the number of positive detections in the last ten sampling events (i.e. 50 samples) are summed and if these total five or more, then they are scored by the tool as not acceptable and control measures are implemented.

Chilling of pig carcasses

Blast chilling is the fast cooling of carcasses by means of blowing cold air. This phase takes place in a room with low ambient temperature. Some *Salmonella* inactivation will take place due to the low temperature and drying of the pig skin. The amount of inactivation is dependent on the temperature and time duration. The pigs then enter the chill/storing phase, keeping the half-carcasses cooled at 4°C for an extended period of time, until the carcasses are transported to the cutting line. *Salmonella* does not grow at 4°C (Bolton *et al*., 2002). Therefore, this phase is not modelled within the hygiene tool.

Conventional pig chilling systems aim to reduce the mean temperature of the side or carcass to approximately 4°C, a temperature considered suitable for cutting or curing. Most producers despatch, cut or commence further processing of the chilled carcass on the day after slaughter, allowing a period of 14 to 16 h for the chilling operation. All chilling methods show similar decreases in bacterial numbers whether conventional air chilling, rapid air chilling or spray chilling of pork carcasses (James *et al*., 1983; Gigiel *et al*., 1989; Greer and Dilts, 1988). Gill and Landers (2004)

found that chilling reduced the numbers of *E. coli* but not the numbers of aerobes on detained carcasses. The rates of carcass chilling are complicated and consist of inputs from intrinsic factors such as carcass mass, fat content and initial carcass temperature as well as extrinsic factors such as chill temperature, air speed, relative humidity and carcass spacing (Sheridan, 2000; Q105). It is important to recognise that chilling has two distinct mechanistic attributes. In addition to reducing temperature, chilling also dries exposed surfaces of carcasses. The reduction of *Campylobacter* numbers on pig carcasses is a consequence of sensitivity to drying as well as freezing temperatures and exposure to an aerobic atmosphere (Stern and Kazmi, 1989; Q108). A study by Botteldoorn *et al.* (2003) found that the levels of *Salmonella* on chilled carcasses varied between three slaughterhouses where chilled carcasses were tested. A single slaughterhouse did not have detectable *Salmonella* on its carcasses whereas at the other end of the scale 36% of carcasses from a different slaughterhouse were positive for *Salmonella* post-chill. In two of the abattoirs studied by Botteldoorn *et al.* (2003) the levels of *Salmonella* decreased as a consequence of chilling. However, in the remaining plant, prevalence increased from 6% to 15%. The reasons for the increase are unclear, although Botteldoorn *et al.* (2003) also detected *Salmonella* from overshoe samples taken from the chiller and thus speculated that the finding may be a consequence of a low temperature-adapted *Salmonella* strain.

Spescha *et al.* (2006) also evaluated the effect of chilling on carcasses. The work was undertaken in the EU and so the findings relate solely to chilling and not a combination of any post process treatments (e.g. organic acid application) combined with chilling. Two slaughterhouses were visited for the work and at both, chilling caused a reduction in numbers of total aerobes and percentage detections of the *Enterobacteriaceae*. Overall, around a single log reduction in numbers of aerobic mesophiles was observed. The reduction was less pronounced at the neck however. It is possible that residual water draining from the carcass across the neck could re-contaminate the neck surface with bacteria. Equally possible, is that reduced air movements toward the chiller floor could mean that chilling and drying was less effective. One possibility is that since an effect of drying is that it causes increased bacterial adherence, a combination of low drying-airflow and water drainage decreases the effectiveness of bacterial adherence making them easier to recover and thereby increasing counts.

Swanenburg *et al.* (2001b) cites tight packing of carcasses during chilling as a possible source of *Salmonella* cross-contamination (Q105-Q106). Additionally, the risk assessment study by Delhalle *et al.* (2008) established that the time taken to get internal carcass temperature down to 7°C ranged between 15 h to 24 h and chilling duration was a significant factor in affecting levels of total aerobic count contamination post chill but the mean increase was only 0.005 log CFU cm^{-2} and therefore of little influence on overall numbers.

Mafu *et al.* (1989) found a high prevalence of *Salmonella* (12.5%) on the chill room floor of a Canadian abattoir, which they attributed to the "*coming and going of workers*" between the slaughter area (25% prevalence) and the chiller and general manual handling of carcasses (Q101-Q104; Q107). Therefore, worker hygiene is important in reducing the risk of *Salmonella* in the chill area.

Some innovative work is currently being undertaken for meat chilling in Australia and may have relevance for local processers. A large amount of practical data regarding the effectiveness of chilling have been turned into a model which is accessed by industry via a custom-coded computer application. One of the main factors influencing the proposal that chilling should be assessed as part of the slaughter dressing process is that the processing throughput of most UK plants is limited by chiller capacity. Chillers loaded at or above capacity do not cool meat as rapidly as chillers loaded at lower stocking densities. If meat is not cooled and dried in a timely manner, growth of indicator bacteria such as *E. coli* can occur in red meat plants (Ross *et al*., 2003; Q108). The "model", which is an easy-to-use computer programme takes the chiller temperature logs as its only input and calculates from them a refrigeration index (RI) value. The value of the RI determines whether chilling proceeded in a satisfactory manner or whether there were conditions experienced by the carcasses that would have allowed the growth of *E. coli* and other material.

Recommendations for processing plant research

- To establish the bacterial status of herds entering the processing plants by direct faecal sampling of gut contents on the processing line and to compare with the results of longitudinal farm studies to define the apparent location of infection (whether on-farm or at the processing plant).
- To investigate the level of carcass contamination within the two main processing plants in Northern Ireland and to assess the hygiene throughout the processing line.
- To correlate carcass contamination and processing line hygiene with the level of risk modelled by the Hygiene Tool.
- To introduce effective control measures and interventions at high risk points throughout the line. Ultimately the actual focus areas will be identified by the investigation to determine the level of carcass contamination and hygiene status throughout the line. However, from the literature, areas where potential intervention may be effective are listed below:
    - Effective cleaning and disinfection of transport lorries – the potential use of phage therapy may be considered
    - Conditions of lairage – i.e. cleaning and disinfection, type of flooring, and spray washing of pigs
    - Stunning and sticking area – i.e. cleaning and disinfection, type of flooring, bleed-out time and knife decontamination
    - Plugging of anus prior to scalding
    - Consideration of a pre-scald stage, scalding conditions (temperature, duration and water renewal) and potential of spray scalding
    - Double singeing and polishing
    - Plugging of rectum and covering of head or early head removal
    - Introduction of a pre-evisceration wash and hot water post-evisceration wash
    - Effective cleaning and disinfection of splitting blade
    - Consideration of steam vacuuming as opposed to knife trimming for faecal contamination
    - Effective chilling conditions and worker hygiene in chill area

Overall conclusions

There are many areas where *Salmonella* prevalence could be reduced throughout production and processing and a whole chain approach is required. This literature review has highlighted that there are several factors associated with *Salmonella* presence on-farm and that there is an urgent need to identify the point of infection on Northern Ireland farms to enable known effective control measures to be implemented. It has also shown that the serological ELISA test is useful in providing information of *Salmonella* presence on farm but that it is of limited use in identifying high-risk pigs at slaughter. A recommendation of this literature review is list the factors associated with *Salmonella* prevalence on-farm in order of priority – this will be completed through a comprehensive producer questionnaire. It is also planned to identify the point of infection on Northern Ireland farms through the completion of a longitudinal study. Once these tasks have been conducted, intervention control measures will be assessed.

Within the processing plant the *Salmonella* carriage at time of slaughter will be quantified to define the prevalence in Northern Ireland herds and also indicate if some pigs present a significantly higher risk than others. The Slaughterhouse Hygiene Tool will be used and correlated with actual microbial contamination. This exercise will provide information on where to target intervention control measures and will ultimately reduce the risk of *Salmonella* contamination within pork products.

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