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# Epidemiology and control measures for *Salmonella* in pigs and pork

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**Abstract**

In order to effectively manage the problem of human salmonellosis attributable to pork and pork products, control measures should be taken simultaneously at all levels of production. These measures require an understanding of the epidemiology of *Salmonella* within and between links of the production chain. Two major factors of pre-harvest *Salmonella* epidemiology are the introduction and subsequent transmission of infection within and between herds. Stress imposed by transportation and the associated handling can significantly increase the number of pigs excreting *Salmonella* upon arrival at the abattoir and during lairage, exposing negative pigs to *Salmonella*. Positive pigs carry *Salmonella* on the skin, in the gastro-intestinal system or in the mouth. The (cross-)contamination of carcasses is basically a matter of redistributing the *Salmonella* bacteria from the positive pigs during the various slaughter processes. Although the manufacturing and retail levels of pork production depend on the quality of raw materials that are delivered, they share the responsibility for the quality and safety of the end products reaching the consumer. At this level and onwards, the three main factors which influence the microbiological quality of meats are handling, time and temperature.


*Keywords:* Feed; Farm; Transport; Lairage; Slaughter; Retail

## 1. Introduction

A range of infections is covered by the term ‘salmonellosis’. The most common type is known as ‘the carrier state’, in which carriage of the organism is not accompanied by symptoms or clinical disease in the host (Murray, 1991). In production animals, these carriers are of importance because they may serve as reservoirs for further spread of infection through shedding and may end up as contaminated end products.

Pork and pork products are recognised as one of the major sources for human salmonellosis. The actual number of human cases of salmonellosis is difficult to assess accurately, even in developed countries. In Denmark, the proportion of human salmonellosis attributable to pork was estimated to be 10 to 15% in 1997 and 1998 (Anonymous, 1998, 1999). Also in The Netherlands, it was estimated that approximately 15% (5–25%) of human cases of

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salmonellosis were associated with the consumption of contaminated pork (Berends et al., 1998).

Currently, the most common perspective on food safety and human salmonellosis is the stable-to-table concept, acknowledging that each link in the food production chain has a share in the responsibility of reducing the risk of foodborne disease (Davies and Funk, 1999). *Salmonella* can enter the food chain at any point throughout its length, from livestock feed, via the on-farm production site, at the slaughterhouse or packing plant, in manufacturing, processing and retailing of food, through catering and food preparation in the home. When considering a surveillance and control programme, it is important to have knowledge of the dynamics of *Salmonella* infections within and between links in the production chain (Lo Fo Wong and Hald, 2000). In this overview, some of the important factors concerning the epidemiology of *Salmonella* from feed to food are discussed.

## 2. Epidemiology of *Salmonella* at feed production

There are two aspects to the relation between the factor feed and *Salmonella* infections in pig herds: (1) feed as a potential source of introduction of *Salmonella*, and (2) the role of feed in the establishment of infection in the animal. The latter is discussed at the pre-harvest phase of pork production. Large quantities of feed are produced, transported and stored daily for use in the pork production industry. Even minor *Salmonella* contamination at this level has the potential to affect many herds. Process control and decontamination steps, such as heat treatment, are essential to avoid the spread of contaminated feed to herds. However, a Danish study could not find a significant difference between pelleted and non-pelleted feed with regard to the presence of *S. enterica*, measured just before being served to finishing pigs (Stege et al., 2000). Davies and Wray (1997) found high levels of *Salmonella* contamination from aggregate inside the cooler area and in fresh wild bird droppings collected from the intake pit areas, the warehouses and outloading gantries in some mills. This illustrates that efforts to keep animal feeds free from *Salmonella* contamination at the time it is presented to the animals requires not only heat treatment of final feed rations, but also securing final feed from any contact with reservoir hosts (e.g. birds, rodents), contaminated raw materials or residual contamination in trucks (Fedorka-Cray et al., 1997a) and storage facilities both at the mill and on the farm.

## 3. Epidemiology of *Salmonella* at pre-harvest

The efforts to control *Salmonella* infection in pigs should be a combination of minimising or preventing exposure to *Salmonella* and maximising pig resistance. The two major factors of pre-harvest *Salmonella* epidemiology involve the introduction of infection and the subsequent transmission within the herd. Pig herds are not closed systems. Herds are subject to the introduction of feed and new stock, and as such are exposed to potential sources of infection. In a European risk factor study (Lo Fo Wong et al., 2001a) it was found that the more supplier herds supplying animals to a finishing herd, the larger the probability of testing animals seropositive in the receiving herd. In the same study, Lo Fo Wong et al. (2001a) found that non-pelleted feed can be considered a protective factor with regard to (the detection of) *Salmonella* infection, compared to pelleted feed. This was also found in other risk factor studies (e.g. Dahl, 1997; Bush et al., 1999). Although heat-treated feed may help prevent the introduction of *Salmonella* to a negative herd, it does not have a controlling effect in herds where *Salmonella* is already present, as non-heat-treated feed stuffs appear to have. The protective effect of offering pigs feeding materials with a low pH, in the form of added organic acids, whey or fermented by-products, against (subclinical) *Salmonella* infections has been discussed in a number of papers (van Schie, 1987; van Winsen et al., 1997; Dahl, 1997). Apart from feed and newly introduced pigs, there are numerous possible routes of infection and transmission, some proven, some hypothesised and difficult to assess. Based on these (potential) risk factors and sources for *Salmonella*, a number of prevention and control options are suggested.

At the herd level, controlling birds, flies and rodents in the stables and storage facilities (Edel et al., 1976; Oosterom, 1991; Muirhead, 1993; Fedorka-Cray et al., 1997b; Harris et al., 1997), as well as keeping pets such as cats and dogs out of the pig house (Borland, 1975), will help prevent the introduction of *Salmonella* from the environment. Avoiding air transmission through dust (e.g. Baggesen et al., 1996) and aerosols (e.g. Lever and Williams, 1996) in indoor facilities, as well as preventing contact with infected wild life (e.g. Euden, 1990) and having limited possibilities for hygienic measures in unconfined (i.e. free-ranging) pig production, presents a challenge with regard to the development of reduction and control strategies (Wingstrand et al., 1999; van der Wolf et al., 2001a). To guard against the co-introduction of *Salmonella* through purchased animals, *Salmonella*-free breeding flocks should be identified or established through a certification system (Oosterom, 1991; Lo Fo Wong et al., 2001b) or through weaning in a clean environment (e.g. Dahl et al., 1997a; Fedorka-Cray et al., 1997b; Nietfeld et al., 1998). In addition, the number of supplier herds should be kept to a minimum (Quessy et al., 1999; Lo Fo Wong et al., 2001a). Batch production (e.g. Pedersen, 1997; Schwartz, 1999; Lo Fo Wong et al., 2001a) with efficient cleaning and disinfection procedures between batches (e.g. Pedersen, 1997; van der Wolf et al., 2001b), in combination with the use of a hygienic lock, i.e. sanitary facilities for washing hands and changing clothes and boots (Fedorka-Cray et al., 1997b; Lo Fo Wong et al., 2001a), should be made standard operating procedure for all European (indoor) pig production to avoid the introduction and/or spread of *Salmonella*, as well as other pathogens, in pig herds.

In the situation where *Salmonella* is present in the herd, some form of acidification of feed or drinking water, be it through fermentation of the feed or the addition of organic acids or whey, can be used as a control or intervention strategy (e.g. Wingstrand et al., 1997; van Winsen et al., 1997; Dahl et al., 1997b; van der Wolf et al., 2001b,c). A change in feed strategy from pelleted feed to non-pelleted feed, fermented wet feed or partially non-heat-treated feed could help lower the exposure of pigs to *Salmonella* and increase pig resistance to infection (e.g. van Schie, 1987; van Winsen et al., 1997; Dahl et al., 1999; Lo Fo Wong et al., 2001a). Closed pen separations of sufficient height are useful in the prevention of the spread of infection between pens (e.g. Dahl et al., 1996; Lo Fo Wong et al., 2001a). There should also be a strategy for managing sick pigs (e.g. Pedersen, 1997). In combination with cleaning between batches (Pedersen, 1997), the formation of re-infection cycles at the pen level can be avoided (e.g. Oosterom, 1991; Berends et al., 1996).

Most single intervention and control measures are not effective enough to reduce or remove a *Salmonella* infection or contamination from a herd. It is therefore recommended that a herd-specific intervention and control strategy is formulated, based on a combination of measures which are both practically and economically feasible in a herd. A multi-factorial infection such as *Salmonella* requires a multi-level approach of intervention and control, i.e. between and within herds, as well as between and within pigs.

## 4. Epidemiology of *Salmonella* during transportation and lairage

*Salmonella*-infected pigs are most often subclinical carriers of *Salmonella* and will only intermittently excrete *Salmonella* bacteria in their faeces (Schwartz, 1999). However, stress may induce carriers to shed *Salmonella* at a higher rate and increase the susceptibility of *Salmonella*-free pigs to infection (Williams and Newell, 1970; Mulder, 1995). During transportation, pigs are subjected to many stress factors, e.g. noise, smells, mixing with ‘unfamiliar’ pigs from other rearing pens or farms, high stocking densities, long duration of transport, change of environmental temperature and a general change of environment (Warriss et al., 1992). Consequently, stress imposed by transportation and associated handling can significantly increase the number of pigs excreting *Salmonella* upon arrival at the abattoir (Williams and Newell, 1970; Berends et al., 1996; Rajkowski et al., 1998). During transportation to the abattoir, *Salmonella*-negative finishing pigs may be infected from previously contaminated trucks that have not been thoroughly cleaned, or from *Salmonella*-infected pigs loaded on the same truck (Williams and Newell, 1970; Childers et al., 1977; Fedorka-Cray et al., 1995; Rajkowski et al., 1998). Furthermore, contaminated trucks may act as a source of infection for other farms or abattoirs (Fedorka-Cray et al., 1994; Rajkowski et al., 1998; Isaacson et al., 1999a,b).

After transport to the abattoir, pigs are usually kept in lairage for a period before killing. This time period can vary considerably in length, but usually most pigs are slaughtered on the day of arrival (Warriss and Bevis, 1986). Besides functioning as a holding area for pigs waiting to be slaughtered, the lairage also allows the pigs to recover from the stressful effects of transport and the associated handling. Many of the same stress factors present during transport are also in force during the waiting time in lairage, and the proportion of pigs shedding *Salmonella* has been shown to increase with the length of time spent in lairage (Morgan et al., 1987b). Furthermore, the lairage is generally only cleaned at the end of the day and is therefore a potential source of contamination of *Salmonella*-negative or low-infected pigs that can easily pick up *Salmonella* from other pigs or the environment either by the oral or nasal route, or by soiling of the skin (Craven and Hurst, 1982; Fedorka-Cray et al., 1995). The longer the time the pigs spend in the lairage the greater is the possibility of contamination and thus the probability of ending up as a positive carcass (Morgan et al., 1987a; Simonsen et al., 1987).

Therefore, to avoid the spread of infection due to transport and lairage, some control measures can be taken. Any mixing of 'unfamiliar' pigs should be avoided and the pigs should be handled as quietly and gently as possible (e.g. Williams and Newell, 1970; Morgan et al., 1987b; Warriss et al., 1992). If possible, batches from a herd should be delivered directly to the slaughterhouse in separate trucks (e.g. Morgan et al., 1987b). It should be ensured that the trucks are thoroughly cleaned and disinfected between each transport (Rajkowski et al., 1998; Swanenburg et al., 2001a).

Lairage time should be kept to an absolute minimum, at least for pigs from *Salmonella*-negative herds (e.g. Morgan et al., 1987b; Warriss, 1996; Swanenburg et al., 2001b; Hald et al., 2001). Also at lairage, a strict separation of batches of pigs should be ensured (e.g. Swanenburg et al., 2001a; Hald et al., 2001) and any mixing of 'unfamiliar' pigs should be avoided. Pigs should be kept in smaller groups ($\leq 15$) (Warriss, 1996). Lairage pens should be cleaned between batches of pigs (e.g. Hald et al., 2001) and, at the end of the slaughter day, thorough cleaning and disinfection should be ensured (e.g. Morgan et al., 1987b; Berends et al., 1996; Hald et al., 2001). Cleaning and disinfection procedures should be monitored by visual and bacteriological control (Hald et al., 2001).

## 5. Epidemiology of *Salmonella* at harvest

Depending on the many influential factors described in the previous sections, the *Salmonella* status of the pigs entering the slaughter line may vary considerably between days or even batches. In most slaughterhouses pig carcasses are dressed with the skin still on. This requires some initial processing of the carcass with the primary purpose of removing the hair. First comes the scalding process, followed by dehairing, singeing and, finally, polishing.

Ordinarily, the number of *Salmonella* spp. is reduced during scalding (Chau et al., 1977; Gill and Bryant, 1992, 1993). However, if the water temperature drops below the recommended 62 °C and/or the amount of organic material is sufficient to protect the bacteria against the heat, the risk of bacteria surviving this process is increased (Sörqvist and Danielsson-Tham, 1990), transforming the scalding process into a critical site of contamination (Simonsen et al., 1987). The dehairing process is commonly regarded by researchers as a site for recontamination of the scalded carcasses (e.g. Simonsen et al., 1987; Gill and Bryant, 1992, 1993; Borch et al., 1996). The rotating flails that are removing the hair may squeeze faeces from the anus, potentially contaminating the equipment with faecal micro-organisms, including *Salmonella* (Borch et al., 1996).

Singeing at 1300–1500 °C (Gracey, 1986) reduces surface contamination of the carcass. However, bacteria in certain areas, such as in the deeper skin folds, the base or orifices of the ears or in the hair follicles, may survive (Berends et al., 1997; Gill, 1998). These bacteria can then be redistributed over the entire carcass during polishing (Simonsen et al., 1987; Gill, 1998; Yu et al., 1999) by the rotating flails and brushes of the polisher. In the dressing process, two processes in particular have been identified as critical control points: the evisceration process, including bung dropping, and the removal of the pluck set (tongue, oesophagus, larynx, trachea, lungs, heart and liver). The carcass splitter is not normally considered to be an important source of carcass contamination (Berends et al., 1997; Gill and Jones, 1997). However, the carcass splitter may become persistently contaminated with *Salmonella* and as such will be a source for carcasses contamination (Sørensen et al., 1999; Hald et al., 2001). In fact, contaminated slaughterhouse equipment seems to play a more important role in the final carcass contamination level than the slaughterhouse personnel (Hald et al., 2001), partly due to the possible build up of bacteria in or on the equipment during working hours (Yu et al., 1999; Hald et al., 2001), especially during warm summer months (Hald et al., 2001). In summary, after a pig has entered the slaughter process, the final *Salmonella* contamination of the dressed carcass originates from one or more of the following sources: the animal itself, from previously slaughtered animals via the processing machinery or slaughterhouse personnel or from persistently contaminated equipment. The final contamination level of carcasses will depend on the combined impact of these probabilities during the day.

Based on the slaughterhouse studies performed by Hald et al. (2001) and Swanenburg et al. (2001a–c), as well as in the literature, a number of prevention and control options are suggested at the slaughterhouse level of pork production. Incoming pigs from *Salmonella*-negative and -infected herds should be slaughtered separately, preferably on different days (e.g. Mousing et al., 1997; Swanenburg et al., 2001a,b), where special hygiene practices should be applied during slaughter of pigs from high-risk herds (e.g. Mousing et al., 1997; Hald et al., 2001). The scalding temperature should be kept at a minimum of 62 °C (e.g. Sörqvist and Danielsson-Tham, 1990; Davies et al., 1999; Hald et al., 2001). Regular cleaning and disinfection of the slaughterhouse equipment, especially of the dehairing and polishing equipment, is necessary to avoid build-up of micro-organisms, including *Salmonella*, and subsequent cross-contamination of carcasses (e.g. Gill and Bryant, 1993; Yu et al., 1999; Sørensen et al., 1999; Hald et al., 2001). During evisceration, a bung bag or a similar device could be used (e.g. Childers et al., 1973; Nesbakken et al., 1994). During the slaughter of pigs from high-risk herds (i.e. known positive herds), the un-split head should be removed early in the process, to avoid carcass contamination from the oral cavity. This may require alternative methods of identification of pigs, e.g. in the case ear tags are used for identification (Christensen and Luthje, 1994). Critical control points should be identified for each slaughterhouse and these points should be monitored (e.g. temperature, bacterial counts, visual inspection, etc.) as part of a HACCP system for contamination of the slaughterline (Hald et al., 2001).

## 6. Epidemiology of *Salmonella* during manufacturing and at retail

Although the manufacturing and retail levels of pork production depend very much on the quality of the raw materials and products that are received, they too bear a responsibility for the quality of the end product and for the prevention of contaminated products reaching the consumer. The three main factors which influence the microbiological quality of meats are handling, time and temperature. Proper and sensible handling of raw materials is vital to successfully avoid cross-contamination between products. In addition, time and temperature abuses may create situations that support the survival and propagation of micro-organisms that may be present in foods.

At the manufacturing and retail levels, large quantities of raw meat of different origin are handled closely together. There may be carcasses and cuts of various pathogenic status present during manufacturing and, moreover, meat from different types of production animals at retail, creating numerous opportunities for cross-contamination or spread of pathogenic micro-organisms. In fact, many conditions, procedures and practices related to food production might have an adverse effect on the safety and subsequent quality of the food. Temperatures experienced during storage and display will affect the product storage/shelf life. If the temperature of meat and meat products is kept sufficiently low (i.e. below 6 °C) during storage and transport to and from the engross/distribution centres, growth of *Salmonella* can be kept to a minimum. However, retail display is possibly the weakest link in the commercial cold chain (James and Bailey, 1990), adding to the concern that *Salmonella* may proliferate to hazardous numbers during periods of temperature abuse in display cases.

Processed pork products may be preserved through acidification, fermentation, curing, smoking, heating, etc., in order to enhance the microbiological stability and to extend the shelf life. These preservation methods are generally based on the control of the initial numbers of bacteria, pH, water activity, microbial competition/interaction, preservatives, oxidation reduction potential, temperature and radiation (Genigeorgis and Sofos, 1999). However, preservation of pork products will also depend on the initial bacterial load. Therefore, also for processed ready-to-eat products, it is essential that the raw materials are of good microbiological quality. With the exception of processing for ready-to-eat products, there are no further decontamination steps at the manufacturing and retail levels of production. Subsequently, the amount of contaminated fresh product in a batch of cuts and carcasses will at best remain the same. It is therefore imperative to identify batches of contaminated animals or product and treat them accordingly (i.e. separate slaughter, heat treatment or destruction) as early in the process as possible. Whereas the consumer level was described as the last line of defence two decades ago (World Health Organisation, 1980), it is important to realise that the retail level is the last 'check-point' at which contaminated end products can be identified.

In accordance with the HACCP principles, it is most important that Good Manufacturing Practice is followed, with regard to hygienic routines and processing procedures, and that storage and display temperatures are monitored regularly. Since subclinically infected humans who are processing or preparing food products constitute a risk of contaminating these products, a necessary step in controlling *Salmonella* at the retail level includes educating the people who are handling the food (Branson and McInerney, 2000). Finally, administration of the origin of meat and meat products is necessary to enable field epidemiologists and public health officials to trace a contamination back to its origin in an outbreak situation.

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