

REVIEW ARTICLE

Prevalence and Risk Factors for Bacterial Food-Borne Zoonotic Hazards in Slaughter Pigs: A Review

J. Fosse^{1,2}, H. Seegers² and C. Magras¹

¹ Food Safety and Microbiology, Veterinary School of Nantes, National Institute of Agronomic Research (INRA), Nantes, France

² Bio-aggression, Epidemiology and Risk Analysis, Veterinary School of Nantes, National Institute of Agronomic Research (INRA), Nantes, France

Impacts

- Food-borne zoonoses are infectious diseases of major health and economic significance in developed countries. In order to protect consumers' health and to enhance the management of food-borne zoonotic agents from primary production to consumption, new regulations have been issued in the European Union. These Regulations notably require information concerning each step from farm to slaughterhouse. Today, pork is the most frequently consumed meat in Europe.
- In this context, the purpose of this review was to collect information on risk factors on pig farms regarding the prevalence of four bacterial hazards responsible for frequent and/or serious pork-borne diseases: *Campylobacter* spp., *Listeria monocytogenes*, *Salmonella enterica* and *Yersinia enterocolitica*. Among the risk factors described in the literature, feed, herd management and biosecurity measures have been shown to greatly impact the prevalence of these hazards. These risk factors may be used as information on the primary production of the pork food chain transmitted from farm to slaughterhouse.
- The application of good hygiene practices in herds is paramount to reduce the risk of presence of food-borne pathogens. As a priority in biosecurity measures, limiting the mixing of pig batches is needed. These measures must be implemented to reduce the presence of pathogens in the first step in the pork food chain.

Keywords:

Pork; food-borne zoonoses; pre-harvest hazard control

Correspondence:

J. Fosse. Unit of Food Safety and Microbiology, Veterinary School of Nantes, BP 40706, 44307 Nantes cedex 3, France.
Tel.: +33 240 687 838;
Fax: +33 240 687 762;
E-mail: j.fosse@vet-nantes.fr

Received for publication March 31, 2008

doi: 10.1111/j.1863-2378.2008.01185.x

Summary

The Hygiene Package and Regulation EC-2160/2003 require information flow from farm to slaughterhouse to enhance European consumers protection in a 'farm to fork' approach. This obligation especially concerns food-borne zoonotic hazards transmitted to humans through pork consumption, such as thermophilic *Campylobacter* spp., *Listeria monocytogenes*, *Salmonella enterica* and *Yersinia enterocolitica*. Prevalence estimates of these four hazards are affected by the sampling strategy and diagnostic procedure. Individual prevalence estimates for pig carriage (from digestive contents or lymph nodes collected at slaughterhouse) were higher than individual prevalence estimates for pig shedding (from faeces). Among risk factors described in the literature, poor pen cleaning and disinfection after pig departure to slaughterhouse and poor bio-security measures are of major significance. Moreover, whereas wet feed increases the risk of pig infection by *L. monocytogenes*, dry feed is a risk factor for *Salm. enterica*. Mixing batches of pigs, notably in fattening herds, represents a risk for the transmission of *Salm. enterica* and *Y. enterocolitica*. Whereas small herds are more infected by thermophilic campylobacters and *Y. enterocolitica*, higher prevalence of *Salmonella* is observed in large herds due to a more frequent mixing of batches. Antibiotic treatment during the finishing period increases

the risk of transmission of *Salm. enterica*. The forenamed elements should be taken into account to characterize farms in a risk assessment approach and to improve zoonotic hazard management in the pork food chain.

Introduction

Pork is the most frequently consumed meat in the European Union (Devine, 2003) and the European pig herd is the second largest in the world after the Chinese herd (ITP, 2003). The management of hazards transmitted to humans by the consumption of pork is therefore of major health and economic significance. The European Commission issued in 2002 the General Food Law¹, a regulation whose main objective is to apply risk analysis to food safety legislation, from primary production to consumption, and in 2003 Regulation EC-2160/2003², whose purpose is the control of food-borne pathogens in Europe. In this context, the management of hazards in the food chain necessitates the interpretation of scientific data on the characteristics and prevalence of hazards defined as 'biological, chemical or physical agents in, or condition of, food or feed with the potential to cause an adverse health effect' (Regulation EC-178/2002, article 3–14). Biological hazards responsible for food-borne zoonoses are of particular concern since their management on farms is possible notably by reducing their digestive carriage – i.e. the presence of hazards in digestive contents – and their faecal shedding (Blaha, 1999; Collins and Wall, 2004; Maunsell and Bolton, 2004; Humphrey and Jørgensen, 2006; Nørrung and Buncic, 2007).

Moreover, the Hygiene Package, which was issued in 2004 and inspired by the requirements of the General Food Law, defines the obligations of food business operators. This package, notably Regulation EC-854/2004³, requires

Member States to develop new meat inspection methods in order to improve consumer health protection. This could be based on the use of food chain information. Indeed, risk-based meat inspection schemes, including information flow from farm to slaughterhouse, seem to be possible in an integrated system (Blaha, 1999; Schruff and Blaha, 2004). Since pig rearing and fattening techniques are standardized, particularly with homogenous market weight ranges and herd breeding methods, new ante mortem indicators of meat inspection could be developed from the integration of data collected on farms, as on-farm prevalence of hazards or risk factors for hazards infection in slaughter pigs. This information may be used to identify high-risk batches for which a thorough macroscopical examination of carcasses (notably to detect faecal contamination) or bacteriological analyses may be carried out. In a risk assessment approach, it is important to collect information on risk factors on farms for hazards which have the greatest impact on public health.

In Europe, twenty-seven biological hazards may be transmitted from pork to consumers (Fosse et al., 2008a). Recent studies on the quantification of the informative value of meat inspection to detect biological hazards transmitted to humans by pork consumption have shown that high risk hazards can not be detected by a macroscopic examination of carcasses (Hamilton et al., 2002; Jelsma et al., 2006; Fosse et al., 2007). Among these hazards, *Yersinia enterocolitica*, *Salmonella enterica*, thermophilic *Campylobacter* spp. and *Listeria monocytogenes* are characterized by the highest scores of risk for pork consumers (Fosse et al., 2008a). Thermophilic *Campylobacter* are gram-negative bacteria growing only within the narrow temperature range from 30 and 47°C (Stanier et al., 1986; Doyle, 1990). They are widely carried in poultry, pig and cattle digestive tracts, without clinical signs (Ono et al., 1995; Weijtens et al., 1999; Magras et al., 2005). *Listeria monocytogenes* is a psychrotroph gram-positive bacterium with an optimal growth temperature of 30–37°C (Stanier et al., 1986; Bahk and Marth, 1990). Numerous studies have shown the asymptomatic carriage of *L. monocytogenes* by pigs (Skovgaard, 1990; Buncic, 1991; Iida et al., 1998). *Salmonella enterica* is a gram-negative mesophilic bacterium with a 37°C optimal growth temperature (Stanier et al., 1986; Doyle and Cliver, 1990a). *Salmonella* infection is mainly subclinical in pigs, with rare septicaemia or enterocolitis reported (Barker and Van Dreumel, 1985). *Yersinia enterocolitica* is a psychrotrophic gram-negative bacteria which can grow at

¹Regulation (EC) 178/2002 of the European Parliament and of the Council of 28 January 2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. *Official Journal of the European Union*, 2002, L 031, 1-24.

²Regulation (EC) 2160/2003 of the European Parliament and of the Council of 17 November 2003 on the control of salmonella and other specified food-borne zoonotic agents. *Official Journal of the European Union*, 2003, L 325, 1-15.

³Regulation (EC) 854/2004 of the European Parliament and of the Council of 29 April 2004 laying down specific rules for the organisation of official controls on products of animal origin intended for human consumption. *Official Journal of the European Union*, 2004, L139, 206-319.

temperatures as low as 0°C and as high as 44°C (Stanier et al., 1986; Doyle and Cliver, 1990b). Pathogenic strains of *Y. enterocolitica* belong to biotypes 1B, 2, 3, 4 and mainly serotypes O:3, O:5, O:8, O:9. They are asymptotically carried in pigs in the digestive tract and in tonsils (Tauxe et al., 1987; Simonet and Catteau, 2005). Pork consumption was shown to be the main cause of human yersiniosis (Tauxe et al., 1987; De Boer and Nouws, 1991; Fredriksson-Ahomaa et al., 2006).

These four bacterial hazards are carried by pigs without clinical signs, i.e. pig infection is characterized by non-apparent digestive carriage – defined here as the presence of hazards in digestive contents other than rectal (gastric, caecal, ileal, colonic) and/or digestive tissues (digestive lymph nodes, tonsils, digestive epithelia) – and faecal shedding defined by the presence of hazards in faeces. Hazards detection by an ante mortem examination is thus not possible (Fosse et al., 2008a). Consequently, the identification of risk factors for food-borne pathogens on a pig farm may be used to improve their control in the pork food chain and to complete hazard management related to meat inspection at slaughterhouses.

The purpose of this review was to sum up the information on prevalence and herd factors statistically linked with prevalence of pigs infected with four bacterial hazards for consumers in Europe: thermophilic *Campylobacter* spp., *L. monocytogenes*, *Salm. enterica* and *Y. enterocolitica*. Prevalences were summarized as: (i) prevalence linked with shedding (prevalence obtained from faeces and/or rectal contents collected on a farm or at a slaughterhouse, respectively); (ii) prevalence linked with digestive carriage (prevalence obtained from digestive contents other than rectal or digestive tissues collected at a slaughterhouse); (iii) serological prevalence (prevalence obtained from antibody detection in blood samples or meat juice). For serological prevalence, only data with the same threshold of detection were included. A summary of risk factors for on farm infection with the hazards was proposed in order to identify characteristics of pig herds which may be taken into account as food chain information from farm to slaughterhouse.

Material and Methods

Literature search methods

A review of the literature was carried out to collect: (i) data on prevalence of pig infections by *Campylobacter* spp., *L. monocytogenes*, *Salm. enterica* and *Y. enterocolitica* on farms, at the end of the fattening period, or upon entering a slaughterhouse; (ii) data on herd prevalence; (iii) information on sources of pig contamination; (iv) risk factors for presence and/or for higher preva-

lence of hazards on farms and pathogen transmission among pigs.

A literature search was conducted using the Commonwealth Abstract Bulletin (CAB) database and Medline for papers indexed since 1990 and the database of the four French National Veterinary Schools libraries for congress proceedings. Searches were performed in April, 2007, November, 2007 and March, 2008. The keyword combination used in the search was: campylobacter or listeria or salmonella or yersinia; and swine or pig; and herd or farm; and risk; or prevalence; in title and/or in abstracts. Searches were restricted to publications from January, 1990 onwards and languages were restricted to English and French. The papers taken into account had: (i) to be original articles; (ii) to report individual or herd prevalence of the food-borne pathogens in indoor-reared fattening pigs, at herd level or upon entering a slaughterhouse, or to define herd risk factors associated with hazards; (iii) to be carried out on samples pointing to faecal shedding, digestive carriage or serological prevalence. Prevalence data on piglets, sows, outdoor-reared pigs or pork carcasses or retail pork were excluded. This search was systematically completed by looking in the reference lists of relevant papers.

The characteristics of study samples and design likely to influence the external validity of the results (sample size, method used for detection – with or without enrichment – individual or pooled analysis, consistency between material and methods and results obtained) were systematically checked and recorded twice by two abstractors, one epidemiologist and one bacteriologist. Data were coded by one abstractor and randomly assessed by a second one. Publications were systematically excluded when prevalence reported was also published by the same authors in other articles (publications or conference proceedings) in order not to repeat data and thus artificially add weight to some values. Besides, when inconsistencies were observed between prevalence or samples size mentioned in abstract, material and method, results or tables, we decided to take into account only data from tables. Cohort studies were also excluded when prevalence in finishing pigs could not be calculated. Therefore, from 236 papers quoted in CAB and Medline databases and analysed, only 106 papers were taken into account to estimate prevalence and summarize risk factors.

Prevalence estimates

For each study, individual or pool and herd apparent prevalence (p) were calculated using the number of positive units and the total sampled units reported in each study. A 95% confidence interval was calculated for each P -value using the formula (Bouyer, 2000):

$$95\% \text{ CI} = p \pm 1.96 \sqrt{\frac{p(1-p)}{n}}$$

with p : apparent prevalence; n : sample size.

Reported apparent prevalence equal to 1 were systematically replaced by a 0.999 value to calculate 95% CI. For each hazard and for each type of material collected (faeces, digestive contents or lymph nodes, blood), median individual and herd prevalence were calculated. For *Y. enterocolitica*, prevalence was calculated only for pathogenic strains.

To calculate individual and herd prevalence summary estimates (p_s), each apparent prevalence was logit-transformed and the standard errors (σ) for logit prevalence were calculated as follows: $\text{logit } p = \ln\left(\frac{p}{1-p}\right)$ and $\sigma = \sqrt{\frac{1}{n \times p \times (1-p)}}$ with p : apparent prevalence; n : sample size.

Reported apparent prevalence equal to 1 were systematically replaced by a 0.999 value. Then a summary estimate of prevalence (p_s) was determined with its 95% confidence interval (95% CI) for each hazard and each type of material collected using the general variance-based method described by Petitti (1994). The formulae for meta-analysis were the following:

$$\text{logit } p_s = \frac{\sum_i \left(w_i \times \ln\left(\frac{p_i}{1-p_i}\right) \right)}{\sum_i w_i} \quad \text{with } w_i = \frac{1}{\sigma_i^2}$$

$$\text{and then } p_s = \frac{e^{\frac{\sum_i \left(w_i \times \ln\left(\frac{p_i}{1-p_i}\right) \right)}{\sum_i w_i}}}{1 + e^{\frac{\sum_i \left(w_i \times \ln\left(\frac{p_i}{1-p_i}\right) \right)}{\sum_i w_i}}}$$

$$95\% \text{ CI logit } p_s = \text{logit } p_s \pm 1.96 \sqrt{\frac{1}{\sum_i w_i}} = [\alpha; \beta]$$

$$\text{and } 95\% \text{ CI } p_s = \left[\frac{e^\alpha}{1 + e^\alpha}; \frac{e^\beta}{1 + e^\beta} \right]$$

$$\text{with } w_i = \frac{1}{\sigma_i^2}$$

where p_i is the apparent prevalence of the i^{th} study and w_i is the weight assigned to the i^{th} study calculated from the standard error (σ_i). Serological prevalence estimates were calculated from data obtained with the same optical density cut-off. Individual prevalence estimates were calculated only from individual analyses. Herd prevalence estimates were calculated from individual and pooled analyses. In

order to assess the relevance of the summary estimates and the heterogeneity of the samples studied, the Q parameter was calculated and compared with a χ^2 distribution with a number of degrees of freedom equal to the number of studies minus 1 (Petitti, 1994). Q was calculated as:

$$Q = \sum_i (w_i (p_s - p_i)^2).$$

Risk factor calculations and summarization

Our purpose was to identify risk factors significantly higher than one. Published risk factors with their 90% confidence intervals were thus collected, notably adjusted odds ratio (OR) when they were available, and when data were lacking, univariate ORs were calculated with their 90% IC as (Bouyer et al., 1995):

$$\text{OR} = \frac{a \times d}{b \times c} \quad \text{and } 90\% \text{ IC OR} = e^{\ln \text{OR} \pm 1.645 \sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{d}}}$$

with (a) the number of exposed positive units; (b) the number of non exposed positive units; (c) the number of exposed negative units; (d) the number of non-exposed negative units. Protective factors (OR <1) identified in papers were transformed into risk factors by calculating their reverse value. When 95% IC OR = $[\alpha; \beta]$ where mentioned in papers, 90% IC = $[\alpha'; \beta']$ were assessed using the relation:

$$\alpha' = e^{\ln \text{OR} - 1.65 \times \frac{\ln \beta - \ln \text{OR}}{1.96}} \quad \text{and } \beta' = e^{\ln \text{OR} + 1.65 \times \frac{\ln \beta - \ln \text{OR}}{1.96}}$$

Risk factors were classified into four categories: biosecurity measures, feed and watering, herd management and health management. For each hazard and each risk factor, ORs were reported and/or calculated in order to identify relevant factors. According to those factors, characteristics of farms associated with were summarized in order to try to distinguish among herds which ones may be considered as high-risk herds.

Thermophilic *Campylobacter* spp.

Prevalence on farms or at slaughterhouse

Campylobacter coli is the main species identified in pigs compared with *C. jejuni* or *C. lari* (Table 1). Prevalence of thermophilic *Campylobacter* spp. in finishing pig ranges according to the nature of the samples studied. As examples, the results of 17 studies in 11 European and North American countries are listed in Table 2. For *Campylobacter* shedding, an individual prevalence estimate of 0.655 was calculated versus 0.710 for digestive carriage (Table 3). Two studies carried out on stomach carriage showed an individual prevalence estimate of 0.515 (Nesbakken et al., 2003; Payot et al., 2004) whereas a prevalence estimate obtained from intestinal

Table 1. Distribution of *Campylobacter* species in finishing pigs reported in eight studies

| Type of material sampled | References | Pigs tested | Herds tested | Type of analysis | Distribution of <i>Campylobacter</i> species (in %) among <i>Campylobacter</i> positive samples | | |
|---|-----------------------------|-------------|--------------|------------------|---|------------------|----------------|
| | | | | | <i>C. coli</i> | <i>C. jejuni</i> | <i>C. lari</i> |
| Faeces collected on farm | Schuppers et al., 2005 | 1,280 | 64 | Pool, Cul | 96.3 | 1.2 | – |
| | Varela et al., 2007a,b | 800 | 80 | Ind, Cul | 99.2 | 0.2 | 0.6 |
| | Fosse et al., 2008b | 215 | 6 | Pool, Nb | 95.3 | 4.7 | 0 |
| Rectal contents collected at slaughterhouse | Minvielle et al., 2007 | 250 | 50 | Ind, Nb | 100 | 0 | 0 |
| | Fosse et al., 2008b | 430 | 6 | Pool, Nb | 100 | 0 | 0 |
| Caecal contents collected at slaughterhouse | Steinhauserova et al., 2005 | 595 | – | Ind, Cul | 92.8 | 7.2 | 0 |
| | Boes et al., 2005 | 1,244 | 247 | Ind, Cul | 97.5 | 2.5 | 0 |
| | Harvey et al., 1999 | 595 | 4 | Ind, Nb | 65.7 | 33.9 | 0.4 |

Ind, individual analysis; Pool, pooled samples analysed; Cul, culture; Nb, culture with numbering; –, lack of data.

contents was higher (0.766). A prevalence estimate obtained from lymph nodes was very low (0.247). One study showed a serological prevalence value of 0.812 (Altrock et al., 2007). Herd prevalence of *Campylobacter* was 1.000 (16 values) except in one study carried out on gastric mucosa with a herd prevalence of 0.830 (Payot et al., 2004).

Sources of infection

A Dutch study showed that parturition enhances faecal shedding of campylobacters in sows with an early contamination of piglets, during the first week of life (Weijtens et al., 1997). Restriction Fragment Length Polymorphism (RFLP)-typing of the isolates collected from sows and piglets showed strong genomic homology between isolates and suggested transmission from sows to offspring (Magras et al., 2004; Laroche et al., 2007). Further studies have shown a higher diversity of strains isolated from finishing pigs than from piglets, suggesting infection of pigs during the fattening period by strains present in pens or intercontamination (Weijtens et al., 1999; Laroche et al., 2007). Thus, piglets are infected at a young age and spread after weaning. The implication of environmental contamination was shown by Weijtens et al. (2000) with the repopulation of an infected farm after an 'empty and clean' period with specific pathogen free pigs, i.e. pigs which have not been contaminated by sows (Weijtens et al., 2000). In this herd, the individual prevalence of faecal shedding was 0.22 versus 0.98 in the control herd, and this prevalence was observed during the whole 20-month long study. Introduction of infection to pigs through vehicular and vectors such as boots and clothes or by contact to rodents and birds was suggested. However, whereas numerous studies have shown the substantial risk of campylobacters infection by contaminated water and feed in poultry (Pearson et al., 1993; Byrd

et al., 2001), this relationship has not been shown for pigs (Magras et al., 2004; Leblanc-Maridor et al., 2008).

Risk factors for shedding and transmission

Few publications have identified risk factors for infection with thermophilic campylobacters in pigs. One recent study carried out by Wehebrink et al. (2007) on 12 fattening farms showed that the prevalence of *Campylobacter* spp. was significantly lower on farms with over 1,000 fattening facilities than on farms with under 1,000 pig fattening facilities (prevalence of 0.743 and 0.800, respectively). Thus, management factors correlated with herd size may have an influence on the occurrence of campylobacters, with higher prevalences in smaller herds. Moreover, in the same study, the following risk factors were reported: housing pigs in separate stalls had a preventive effect, similar to antibiotic treatment at the beginning of the fattening period, whereas anthelmintic treatment seemed to increase the risk of detection of campylobacters (Wehebrink et al., 2007).

Listeria monocytogenes

Prevalence on farms or at slaughterhouses

In Denmark, Skovgaard and Nørrung (1989) showed *L. monocytogenes* faecal shedding prevalence of 0.017 from 172 pigs collected at slaughterhouses. A French study carried out by Beloeil et al. (2003a) showed the presence of *L. monocytogenes* in 14% of pig batches ($n = 93$) with a detection of bacteria on pooled perianal swabs after the enrichment step. Cereser et al. (2007) did not show the presence of *L. monocytogenes* in the rectal content of 70 pigs collected at slaughterhouses. Nevertheless, the method used was the numbering ISO 11290-1 method, without a preliminary enrichment step and thus a lower threshold of detection. In a Japanese study carried out on

Table 2. Prevalence of *Campylobacter* spp. in finishing pigs reported in 17 studies in 11 European and North-American countries

| Shedding or carriage | Country | References | Individual or pool prevalence | | Pigs tested | Herd prevalence | | Type of material sampled | Type of analysis | |
|--|-----------------------|------------------------------|-------------------------------|-------------|-------------|-----------------|---------------|--|------------------------------|-------------|
| | | | p | p 95% CI | | p | p 95% CI | | | |
| | | | | | | | | | | Lower limit |
| Shedding (prevalence in faeces or rectal contents) | Belgium | Botteldoorn et al., 2001 | 0.340 | 0.264 0.416 | 150 | 1.000 | 0.968 1.000 | Rectal swabs collected on farm | Ind, Cul | |
| | Canada | Varela et al., 2007a,b | 0.999 | 0.997 1.000 | 800 | 1.000 | 0.992 1.000 | Fresh faeces (10 g) collected on farm | Ind, Cul | |
| | France | Minvielle et al., 2007 | 1.000 | 0.995 1.000 | 250 | 1.000 | 0.990 1.000 | Rectal contents (5 g) collected at slaughterhouse | Ind, Nb | |
| Digestive carriage (prevalence in digestive contents or tonsils and lymph nodes collected at slaughterhouse) | Germany | Fosse et al., 2008b | 1.000 | 0.995 1.000 | 215 | 1.000 | 0.974 1.000 | Faeces (25 g) collected on farm | Pool, Nb | |
| | | Alter et al., 2005 | 0.791 | 0.747 0.835 | 330 | 1.000 | 0.977 1.000 | Rectal contents (25 g) collected at slaughterhouse | Pool, Nb | |
| | Italy | Alitrock et al., 2007 | 0.697 | 0.666 0.726 | 900 | 1.000 | 0.988 1.000 | Faeces (5 g) collected on farm | Ind, Cul | |
| | Norway | Wehebrink et al., 2007 | 0.647 | 0.617 0.675 | 1,040 | - | - | Faeces collected on farm | Ind, Cul | |
| | Switzerland | Cereser et al., 2007 | 0.114 | 0.040 0.188 | 70 | 1.000 | - | Faeces or rectal swabs collected on farm | Ind, Cul | |
| Serological prevalence | United States | Nesbakken et al., 2003 | 1.000 | 0.986 1.000 | 24 | 1.000 | 0.963 1.000 | Rectal (25 g) contents collected at slaughterhouse | Ind, Cul | |
| | | Schuppers et al., 2005 | 0.957 | 0.944 0.967 | 1,280 | 1.000 | 0.991 1.000 | Rectal contents (10 g) collected at slaughterhouse | Ind, Cul | |
| | Czech Republic | Gebreyes et al., 2005 | 0.558 | 0.502 0.614 | 300 | 1.000 | 0.979 1.000 | Pooled faeces (5 × 5 g) collected on farm | Pool, Cul | |
| | | Steinhausserova et al., 2005 | 0.491 | 0.451 0.531 | 595 | - | - | Fresh faeces (10 g) collected on farm | Ind, Cul | |
| | Denmark | Boes et al., 2005 | 0.920 | 0.904 0.934 | 1,244 | 1.000 | 0.969 1.000 | Caecal contents | Ind, Cul | |
| | | Payot et al., 2004 | 0.504 | 0.441 0.567 | 240 | 0.833 | 0.684 0.982 | Caecal contents (100 ml) | Ind, Cul | |
| | Norway | Cereser et al., 2007 | 0.073 | 0.012 0.134 | 70 | 1.000 | - | Gastric mucosa samples (9 cm ²) | Ind, Cul | |
| | | Nesbakken et al., 2003 | 0.458 | 0.259 0.657 | 70 | 1.000 | - | Mesenteric lymph nodes (25 g) | Ind, Cul | |
| | the Netherlands | United States | Wijitens et al., 1993 | 0.850 | 0.772 0.928 | 80 | 1.000 | 0.977 1.000 | Tonsils (10 g) | Ind, Nb |
| | | | Harvey et al., 1999 | 0.916 | 0.915 0.917 | 595 | 1.000 | 0.326 0.994 | Mesenteric lymph nodes (5 g) | Ind, Nb |
| Germany | | Alitrock et al., 2007 | 0.812 | 0.785 0.836 | 900 | 1.000 | 0.988 1.000 | Stomach contents (10 g) | Ind, AD | |
| | | the Netherlands | Wijitens et al., 1993 | 0.850 | 0.772 0.928 | 80 | 1.000 | 0.977 1.000 | Ileal contents (10 g) | Ind, Nb |
| | | | | 0.916 | 0.915 0.917 | 595 | 1.000 | 0.326 0.994 | Caecal contents (10 g) | Ind, Nb |
| | | Germany | Alitrock et al., 2007 | 0.812 | 0.785 0.836 | 900 | 1.000 | 0.988 1.000 | Colon contents (10 g) | Ind, Nb |
| Germany | Alitrock et al., 2007 | 0.812 | 0.785 0.836 | 900 | 1.000 | 0.988 1.000 | Blood samples | Ind, AD | | |

P, apparent prevalence; Ind, individual analysis; Pool, pooled samples analysed; Cul, culture; AD, antibody detection; Nb, culture with numbering; -, lack of data.

Table 3. Summary of prevalence of the four high-risk food-borne zoonotic hazards in finishing pigs reported in 80 studies

| Nature of sample tested or type of shedding | Individual prevalence | | | | | | | | | | Herd prevalence | | | | | | | | | |
|--|-----------------------|-------|-------|----------------|-------------|-------------|---------|--------|----|--------|-----------------|-------|----------------|-------------|-------------|---------------------|-------|----|--|--|
| | Median | Min | Max | p _s | Lower limit | Upper limit | Q | Pv | n | Median | Min | Max | p _s | Lower limit | Upper limit | Q | Pv | n | | |
| | | | | | | | | | | | | | | | | | | | | |
| <i>Campylobacter</i> spp. | 0.697 | 0.114 | 0.999 | 0.655 | 0.646 | 0.664 | 8.222 | 0.412 | 9 | 1.000 | 1.000 | 1.000 | 0.999 | 0.996 | 1.000 | 0.000 | 1.000 | 11 | | |
| Shedding (faeces or rectal contents) | | | | | | | | | | | | | | | | | | | | |
| Digestive carriage | 0.738 | 0.073 | 0.958 | 0.710 | 0.699 | 0.720 | 19.222 | 0.057 | 12 | 0.999 | 0.830 | 1.000 | 0.877 | 0.809 | 0.923 | 0.011 | 1.000 | 5 | | |
| Gastric contents | 0.565 | 0.504 | 0.625 | 0.515 | 0.484 | 0.545 | 0.075 | 0.784 | 2 | 0.830 | - | - | 0.830 | 0.739 | 0.794 | - | - | 1 | | |
| Intestinal contents | 0.920 | 0.549 | 0.958 | 0.766 | 0.755 | 0.776 | 14.618 | 0.023 | 7 | 1.000 | 1.000 | 1.000 | 0.999 | 0.993 | 1.000 | 0.000 | 1.000 | 3 | | |
| Tonsils and digestive lymph nodes | 0.292 | 0.073 | 0.458 | 0.247 | 0.203 | 0.297 | 0.418 | 0.811 | 3 | 1.000 | - | - | 0.999 | - | - | - | - | 1 | | |
| Serological prevalence | 0.812 | - | - | 0.812 | 0.799 | 0.825 | - | - | 1 | 1.000 | - | - | 0.999 | 0.994 | 1.000 | - | - | 1 | | |
| <i>Listeria monocytogenes</i> | 0.009 | 0 | 0.017 | 0.017 | 0.009 | 0.030 | 0.000 | 1.000 | 2 | 0.140 | - | - | 0.140 | 0.108 | 0.180 | - | - | 1 | | |
| Shedding (faeces or rectal contents) | | | | | | | | | | | | | | | | | | | | |
| Digestive carriage: | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| Gastric contents | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| Intestinal contents | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| Tonsils and digestive lymph nodes | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| Serological prevalence | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| <i>Salmonella enterica</i> | 0.039 | 0.007 | 0.340 | 0.062 | 0.060 | 0.064 | 8.300 | 0.600 | 11 | 0.416 | 0.101 | 0.999 | 0.218 | 0.211 | 0.225 | 14.214 | 0.942 | 25 | | |
| Shedding (faeces or rectal contents) | | | | | | | | | | | | | | | | | | | | |
| Digestive carriage: | 0.145 | 0.018 | 0.547 | 0.155 | 0.153 | 0.157 | 84.818 | 0.000 | 29 | 0.554 | 0.028 | 0.999 | 0.234 | 0.227 | 0.240 | 23.436 | 0.219 | 20 | | |
| Gastric contents | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | | |
| Intestinal contents | 0.202 | 0.018 | 0.547 | 0.246 | 0.242 | 0.251 | 35.028 | 0.001 | 14 | 0.500 | 0.028 | 0.999 | 0.190 | 0.183 | 0.197 | 8.304 | 0.599 | 11 | | |
| Tonsils and digestive lymph nodes | 0.108 | 0.033 | 0.332 | 0.109 | 0.107 | 0.111 | 31.115 | 0.005 | 15 | 0.640 | 0.191 | 0.919 | 0.372 | 0.355 | 0.389 | 10.334 | 0.242 | 9 | | |
| Serological prevalence: | 0.142 | 0.016 | 0.470 | 0.081 | 0.081 | 0.081 | 281.337 | <0.001 | 12 | 0.773 | 0.047 | 0.951 | 0.124 | 0.120 | 0.128 | 62.064 ^A | - | 15 | | |
| Blood samples (10% OD cut-off) | 0.313 | 0.156 | 0.470 | 0.367 | 0.361 | 0.373 | 28.376 | <0.001 | 2 | 0.920 | 0.890 | 0.950 | 0.898 | 0.882 | 0.912 | 0.012 | 0.913 | 2 | | |
| Blood samples (25% OD cut-off) | 0.253 | - | - | 0.253 | 0.233 | 0.275 | - | - | 1 | 0.812 | 0.773 | 0.850 | 0.781 | 0.747 | 0.812 | 0.014 | 0.906 | 2 | | |
| Blood samples (30% OD cut-off) | 0.099 | - | - | 0.099 | 0.096 | 0.102 | - | - | 1 | 0.367 | - | - | 0.367 | 0.349 | 0.386 | - | - | 1 | | |
| Blood samples (40% OD cut-off) | - | - | - | - | - | - | - | - | 1 | 0.230 | - | - | 0.230 | 0.190 | 0.276 | - | - | 1 | | |
| Meat juice samples (20% OD cut-off) | 0.082 | - | - | 0.082 | 0.082 | 0.082 | - | - | 1 | 0.833 | - | - | 0.833 | 0.625 | 0.937 | - | - | 1 | | |
| Meat juice samples (25% OD cut-off) | 0.274 | 0.115 | 0.432 | 0.296 | 0.279 | 0.313 | 3.622 | 0.057 | 2 | 0.900 | - | - | 0.900 | 0.810 | 0.950 | - | - | 1 | | |
| Meat juice samples (30% OD cut-off) | 0.283 | - | - | 0.283 | 0.278 | 0.288 | - | - | 1 | 0.450 | - | - | 0.450 | 0.400 | 0.501 | - | - | 1 | | |
| Meat juice samples (40% OD cut-off) | 0.062 | 0.016 | 0.152 | 0.055 | 0.054 | 0.055 | 3.159 | 0.368 | 4 | 0.210 | 0.047 | 0.667 | 0.049 | 0.047 | 0.051 | 0.911 | 0.823 | 4 | | |
| Pathogenic strains of <i>Yersinia enterocolitica</i> | 0.125 | 0.005 | 0.196 | 0.122 | 0.118 | 0.125 | 0.672 | 0.999 | 8 | 0.666 | 0.357 | 0.999 | 0.599 | 0.557 | 0.640 | 0.684 | 0.998 | 8 | | |
| Shedding (faeces or rectal contents) | 0.147 | 0.038 | 0.625 | 0.194 | 0.189 | 0.199 | 11.156 | 0.800 | 17 | 0.584 | 0.122 | 0.999 | 0.269 | 0.245 | 0.295 | 2.510 | 0.999 | 14 | | |
| Digestive carriage: | 0.042 | - | - | 0.042 | 0.016 | 0.108 | - | - | 1 | 0.333 | - | - | 0.333 | 0.128 | 0.630 | - | - | 1 | | |
| Gastric contents | 0.125 | 0.040 | 0.173 | 0.165 | 0.156 | 0.175 | 0.119 | 0.998 | 5 | 0.500 | 0.122 | 0.667 | 0.141 | 0.119 | 0.167 | 0.402 | 0.940 | 4 | | |
| Intestinal contents | 0.219 | 0.038 | 0.625 | 0.203 | 0.197 | 0.209 | 10.542 | 0.482 | 12 | 0.585 | 0.250 | 0.999 | 0.396 | 0.357 | 0.436 | 1.139 | 0.999 | 10 | | |
| Tonsils and digestive lymph nodes | | | | | | | | | | | | | | | | | | | | |
| Serological prevalence | 0.668 | 0.541 | 0.875 | 0.699 | 0.325 | 0.918 | 0.007 | 0.997 | 3 | 0.883 | 0.640 | 0.999 | 0.653 | 0.627 | 0.678 | 0.148 | 0.929 | 3 | | |

Min, minimal value; Max, maximal value; p_s, prevalence estimate; n, number of values per category; -, lack of data; Pv, P-value for the calculated Q parameter in comparison with a χ^2 distribution; OD, optical density.

caecal contents of 250 pigs from the same herd collected at a slaughterhouse, digestive carriage prevalence of 0.3 was observed (Yokoyama et al., 2005).

Sources of infection

The main source of pig contamination by *L. monocytogenes* described is feed. Indeed, a few studies have shown that wet feed is associated with a higher prevalence of shedding than dry feed (Skovgaard and Nørrung, 1989; Beloil et al., 2003a). It may be explained by the more frequent presence of *L. monocytogenes* in wet feed than in dry feed (Beloil et al., 2003b) due to the contamination of pipelines used for the distribution of wet feed. The modification of pig digestive bacterial flora due to wet feed with development of *L. monocytogenes* may be another explanation. Environmental contamination may also be possible, because of the telluric origin of *L. monocytogenes* (Beloil et al., 2003a).

Risk factors for shedding and transmission

Wet feed and inefficient biosecurity measures are described as risk factors regarding the presence of *L. monocytogenes* (Table 4). Pipeline cleaning and disinfection is notably associated with a higher prevalence of *Listeria* shedding (Beloil et al., 2003a). Indeed, disinfection may destroy bacterial pipeline biofilm which may inhibit the development of *L. monocytogenes* (Royer et al., 2004).

Salmonella enterica

Prevalence on farm or at slaughterhouse

A meta-analysis carried out from 98 references showed the influence of sampling design and a diagnostic test used on prevalences published (Sanchez et al., 2007).

Using pooled faecal samples for bacteriological detection of *Salmonella* proved to be more sensitive than individual detection (Arnold et al., 2006). Thus, individual prevalence in Europe and North America showed great differences depending on the nature and the volume of samples analysed and the type of analysis. As examples, the results of 46 studies in 15 European and North American countries are listed in Table 5. An individual prevalence estimate of 0.062 was calculated for *Salmonella* shedding with a herd prevalence estimate of 0.218 (Table 3). *Salmonella enterica* prevalence in digestive lymph nodes was estimated at 0.109 versus 0.242 in digestive contents collected at slaughterhouses. An individual serological prevalence estimate of 0.081 was obtained. Individual serological prevalence estimates ranged from 0.099 to 0.367 for blood samples according to the optical density cut-off. Such a variation is observed for meat juice (from 0.055 to 0.296). A serological herd prevalence estimate of 0.124 was calculated (from 0.773 to 0.950 for blood samples and from 0.047 to 0.667 for meat juice, according to optical density cut-off). Inconsistently, farm bacteriological data showed a mean herd prevalence of 0.209.

Numerous studies have shown an increase in prevalence from farm to slaughterhouse (Craven and Hurst, 1982; Warris, 1992; Mulder, 1995; Hurd et al., 2004; Fosse et al., 2008b) notably explained by the impact of transport and the lairage period. Stress during transport may enhance shedding of *Salmonella* by non-apparent carriers and then the infection of trucks or interinfection of pigs during lairage (Fravallo et al., 1999).

Sources of infection

An increase in *Salmonella* shedding at weaning was observed in sows (Nollet et al., 2005) and in piglets, nota-

Table 4. Summary of risk factors for *Yersinia enterocolitica* shedding on pig farms reported in two studies.

| | Risk factor of presence of <i>Yersinia enterocolitica</i> | | Reference | OR [90%CI] |
|----------------------|---|---|----------------------|-----------------|
| Biosecurity measures | Ventilation | Lack of under-pressure ventilation | Skjerve et al., 1998 | 3.0* [1.5–6.2] |
| | Presence of domestic animals | Daily observation of cats with kittens | Skjerve et al., 1998 | 2.4 [1.3–4.6] |
| Feed | Water and feed | Detection of <i>Yersinia enterocolitica</i> in water or feed | Pilon et al., 2000 | NE |
| | Distribution of feed | Manual distribution of feed correlated to a small herd size (<1000 pigs) | Skjerve et al., 1998 | 2.3* [1.3–3.9] |
| Herd management | Litter | Straw on floor | Skjerve et al., 1998 | 2.3 [1.2–4.3] |
| | Herd type | Mix of pigs from different origins in fattening herds versus farrow-to-finish herds | Skjerve et al., 1998 | 6.7* [3.5–12.7] |
| | Transport | Carriage of pigs to slaughterhouse in personal vehicles (correlated to a small herd size) | Skjerve et al., 1998 | 12.9 [2.2–74.2] |

NE: not possible to estimate.

*Calculated OR from published data.

Table 5. Summary of risk factors for *Listeria monocytogenes* shedding on pig farms reported in two studies

| Risk factor of presence of <i>Listeria monocytogenes</i> | | OR [90%CI] | Reference | |
|--|---|---|------------------|----------------------|
| Biosecurity | Change room | Lack of change room at the entrance of facilities | 7.7 [1.2–49.7] | Beloil et al., 2003a |
| | Boot disinfection | Frequency of boot disinfection inferior to once a week | 4.7 [1.4–15.6] | Beloil et al., 2003a |
| | 'Empty and clean' period | An 'empty and clean' period of one day or less between two fattening batches | 3.5 [1.4–11.8] | Beloil et al., 2003a |
| Feed | Wet feed | <i>L. monocytogenes</i> was isolated from 19.3% of the 57 wet feed batches studied versus 5.9% of the 36 dry feed batches | 4.4 [1.1–17.2] | Beloil et al., 2003a |
| | | <i>Listeria</i> spp. was isolated from 93% of the 27 wet fed pens studied versus 50% of 20 dry fed pens | 12.5* [7.0–22.4] | Beloil et al., 2003b |
| | Cleaning of pipelines used for wet feed | Pipeline cleaning and disinfection | 8.4* [4.7–15.1] | Beloil et al., 2003a |

*Calculated OR from published data.

bly due to feed transition and a decrease in sow colostral antibodies (Kranker et al., 2003). A progressive increase in *Salmonella* shedding was also suggested in one American study involving a cohort of finishing pigs (Davies et al., 1999). Transmission of *Salmonella* to pigs through contaminated feed or environment was described (Hurd et al., 2001; Langvad et al., 2006). A study carried out by Fablet et al. (2003b) showed a close link between residual contamination of fattening rooms after a 'clean and empty' period and the level of infection of fattening pigs before slaughtering. The rapid infection of pigs from 2 to 3 h after contact with *Salmonella* was also described (Hurd et al., 2001). Contact with persons, contaminated slurry or sharing contaminated equipment were also proven to be risk factors for the transmission of *Salmonella* between pigs herds and from cattle to pigs herds (Langvad et al., 2006). *Salmonella enterica* was also isolated from rodents in pig herds (Le Moine et al., 1987).

Moreover, Fablet et al. (2003b) showed that dry feed enhanced the risk of *Salmonella* shedding compared to wet feed. The acidification of intestinal content inhibiting the development of *Salmonella* due to wet feed is an explanation (Fablet et al., 2003b; Royer et al., 2004). The direct infection of pigs through contaminated feed may be another explanation. A Canadian study showed the presence of *Salmonella* in 25 of the 420 (0.059) dry feed samples versus 3 of the 400 (0.008) wet ones (Friendship et al., 2006). This study also showed the presence of *Salmonella* in 38% of the 21 herds using dry feed versus 15% of the 20 herds using wet feed. Nevertheless, an American study carried out by Funk et al. (2001a) showed that only 2 out of 800 feed samples tested were contaminated by *Salmonella* (0.003).

Among all factors explaining *Salmonella* status in pig herds, Fablet et al. (2003a) showed in a study carried out in 105 herds that hygiene measures in farrowing rooms had an impact on *Salmonella* occurrence. Indeed, not emptying pits below floors of farrowing rooms after

the removal of previous batches of sows and the removal of manure less than twice a day were associated with higher *Salmonella* shedding at the end of the fattening period. Studies highlighted the implication of infection status of sows on *Salmonella* infection in fattening pigs (Kranker et al., 2001; Lurette et al., 2007). Besides, a serological study carried out by Merialdi et al. (2007) showed a high level of seropositivity in sows (from 0.938 to 1) and a progressive increase of seropositivity in pigs during farrowing, post-weaning and fattening periods. The infection of pigs at the beginning of the fattening period was suggested by this study. Moreover, a variation in individual susceptibility was suggested to explain differences in levels of infection between herds (Kranker et al., 2003).

Risk factors for shedding and transmission

Among all the risk factors of *Salm. enterica* shedding on farms described in the literature, dry feed and lack of biosecurity measures are mainly reported (Table 6). A Danish study showed that *Salm. enterica* may increase the risk of diarrhoea in pigs (Møller et al., 1998). Thus, digestive clinical signs may be considered risk factors for the presence of *Salmonella* in pigs. Preventive antibiotic treatment during the fattening period is also described to enhance the risk of *Salmonella* shedding (Rossel et al., 2006). Nevertheless, on the contrary, an American study showed a higher prevalence of *Salmonella* in antimicrobial-free production systems than in conventional systems (Gebreyes et al., 2006). Variations of antibiotic doses used for therapy or as probiotics may explain such differences.

Yersinia enterocolitica

Prevalence on farms and at slaughterhouses

Prevalence figures in pigs greatly depend on the type of material sampled and the diagnostic test applied (Table 7).

Table 6. Prevalence of *Salmonella enterica* in finishing pigs reported in 46 studies in 15 European and North American countries

| Shedding or carriage in faeces or rectal contents) | Country | Reference | Individual or pool prevalence | | | Herd prevalence | | | Type of material sampled | Type of analysis | | |
|---|---|---------------------------|----------------------------------|----------------|----------------|-----------------|----------------|----------------|--------------------------|--------------------------------|---|-----------|
| | | | p | p 95% CI | | p | p 95% CI | | | | | |
| | | | | Lower limit | Upper limit | | Lower limit | Upper limit | | | | |
| Shedding (prevalence in faeces or rectal contents) | Belgium | Botteldoorn et al., 2001 | 0.070 | 0.036 | 0.104 | 0.250 | 0.000 | 0.674 | 4 | Rectal swabs collected on farm | Ind, Cul | |
| | Canada | Rajic et al., 2005 | 0.143 | 0.124 | 0.162 | 1,344 | 0.511 | 0.408 | 0.614 | 90 | Faeces collected (5 × 5 g) on farm on floors | Pool, Cul |
| Denmark | France | Farzan et al., 2006 | 0.034 | 0.022 | 0.046 | 820 | 0.136 | 0.061 | 0.211 | 81 | Faeces (25 g) collected on farm | Ind, Cul |
| | | Steger et al., 2000 | - | - | - | - | 0.101 | 0.035 | 0.167 | 79 | Faeces (5 × 5 g) collected on farm | Pool, Cul |
| | | Fablet et al., 2003a | - | - | - | - | 0.362 | 0.270 | 0.454 | 105 | Faeces collected on fattening rooms floors by swabbing (10 m ²) | Pool, Cul |
| | | Fablet et al., 2007 | - | - | - | - | 0.189 | 0.093 | 0.285 | 64 | Faeces (25 g) collected on farm | Pool, Cul |
| | | Fosse et al., 2008b | 0.023 | 0.003 | 0.043 | 215 | 0.167 | 0.000 | 0.465 | 6 | Faeces (25 g) collected on farm | Pool, Cul |
| | | | 0.314 | 0.270 | 0.358 | 430 | 0.833 | 0.535 | 1.000 | 6 | Rectal contents (25 g) collected at slaughterhouse | Pool, Cul |
| | Germany | Steinbach et al., 2002 | 0.037 | 0.034 | 0.040 | 11,960 | 0.200 | 0.170 | 0.230 | 679 | Rectal contents collected at slaughterhouse | Ind, Cul |
| | Hungary | Biksi et al., 2007 | 0.215 | 0.181 | 0.249 | 558 | 0.548 | 0.373 | 0.723 | 31 | Faeces collected on farm | Pool, Cul |
| | Ireland | Rowe et al., 2003 | - | - | - | - | 0.508 | 0.380 | 0.636 | 59 | Faeces (25 g) collected on farm | Pool, Cul |
| | | Duggan et al., 2007 | 0.340 | 0.263 | 0.417 | 147 | 0.889 | 0.684 | 1.000 | 9 | Rectal contents (25 g) collected at slaughterhouse. | Ind, Cul |
| | Italy | Cereser et al., 2007 | 0.028 | 0.000 | 0.067 | 70 | 1.000 | - | - | 1 | Rectal contents (25 g) collected at slaughterhouse | Ind, Cul |
| | | Cibin et al., 2007 | 0.276 | 0.231 | 0.321 | 381 | - | - | - | - | Faeces (5 g) collected at slaughterhouse | Ind, Cul |
| | Spain | Mejia et al., 2006 | 0.021 | 0.015 | 0.027 | 2,187 | 0.204 | 0.130 | 0.278 | 113 | Pooled faeces (25 g) collected on floor on farm | Pool, Cul |
| | | Garcia-Feliz et al., 2007 | 0.125 | 0.112 | 0.138 | 2,320 | 0.431 | 0.367 | 0.495 | 232 | Faeces (pools of 5 × 5 g) collected on floor on farm | Pool, Cul |
| | Denmark, Germany, Greece, The Netherlands | Lo Fo Wong et al., 2003 | 0.093 | 0.078 | 0.108 | 1,455 | 0.416 | 0.306 | 0.526 | 77 | Pen faecal samples (5 × 5 g) collected on farm | Pool, Cul |
| | United-Kingdom | Davies et al., 2003 | 0.328 | 0.280 | 0.376 | 369 | 0.900 | 0.769 | 1.000 | 20 | Faeces (30 g) collected on floor | Pool, Cul |
| | United-States | Barber et al., 2002 | - | - | - | 720 | 0.750 | 0.505 | 0.995 | 12 | Faeces (1 g) collected on farm | Ind, Cul |
| | | Hurd et al., 2004 | 0.011 | 0.000 | 0.023 | 280 | 0.667 | 0.290 | 1.000 | 6 | Faeces (1 g) collected on farm | Ind, Cul |
| | | | 0.007 | 0.000 | 0.017 | 281 | 0.167 | 0.000 | 0.465 | 6 | Rectal contents (1 g) collected on farm | Ind, Cul |
| | | | 0.252 | 0.202 | 0.302 | 286 | 1.000 | 0.974 | 1.000 | 6 | Faeces (1 g) collected at slaughterhouse | Ind, Cul |

Table 6. Continued

| Shedding or carriage | Country | Reference | Individual or pool prevalence | | | Herd prevalence | | | Type of material sampled | Type of analysis | | |
|--|----------------|--|-------------------------------|-------------|-------------|-----------------|-------------|-------------|--------------------------|------------------|--|-----------|
| | | | p | p 95% CI | | p | p 95% CI | | | | | |
| | | | | Lower limit | Upper limit | | Lower limit | Upper limit | | | | |
| | | Bahnson et al., 2006b | 0.049 | 0.035 | 0.063 | 934 | 0.159 | 0.069 | 0.249 | 63 | Faeces collected on farm | Ind, Cul |
| | | | 0.039 | 0.027 | 0.051 | 937 | 0.222 | 0.119 | 0.325 | 63 | Rectal contents (20 g) collected at slaughterhouse | Ind, Cul |
| Digestive carriage (prevalence in digestive contents or tonsils and lymph nodes collected at slaughterhouse) | Belgium | Korsak et al., 2003 | 0.473 | 0.401 | 0.545 | 186 | - | - | - | 13 | Colon contents (25 g) | Pool, Cul |
| | | Nollet et al., 2004 | 0.332 | 0.311 | 0.353 | 1,860 | 0.919 | 0.851 | 0.987 | 62 | Gut lymph nodes (10 g) | Ind, Cul |
| | Canada | Letellier et al., 1999a | 0.052 | 0.040 | 0.064 | 1,420 | 0.028 | 0.006 | 0.050 | 223 | Caecal contents (1 g) | Ind, Cul |
| | Denmark | Baggesen et al., 1996 | 0.062 | 0.058 | 0.066 | 13,468 | 0.222 | 0.200 | 0.244 | 1,363 | Caecal contents (5 g) | Pool, Cul |
| | | Christensen et al., 2002 | - | - | - | - | 0.114 | 0.100 | 0.128 | 1,962 | Caecal contents (25 g) | Ind, Cul |
| | | Sørensen et al., 2004 | 0.130 | 0.114 | 0.146 | 1,658 | - | - | - | - | Caecal contents (25 g) | Ind, Cul |
| | France | Beloeil et al., 2004b | 0.108 | 0.093 | 0.123 | 1,666 | - | - | - | - | Caecal lymph nodes (25 g) | Ind, Cul |
| | Germany | Kásbohrer et al., 2000; Steinbach et al., 2002 | 0.248 | 0.222 | 0.274 | 1,030 | 0.703 | 0.614 | 0.792 | 101 | Caecal contents (25 g) | Ind, Cul |
| | | Nowak et al., 2007 | 0.033 | 0.030 | 0.036 | 11,960 | 0.191 | 0.161 | 0.221 | 679 | Gut lymph nodes | Ind, Cul |
| | | | 0.165 | 0.128 | 0.202 | 393 | 0.344 | 0.179 | 0.509 | 32 | Jejunum lymph nodes (10 g) | Ind, PCR |
| | | | 0.155 | 0.093 | 0.217 | 129 | - | - | - | - | Tonsils | Ind, Cul |
| | Ireland | Quirke et al., 2001 | 0.146 | 0.112 | 0.180 | 419 | 0.500 | 0.359 | 0.641 | 48 | Caecal contents (1 g) | Ind, Cul |
| | | Duggan et al., 2007 | 0.469 | 0.388 | 0.550 | 147 | 0.889 | 0.684 | 1.094 | 9 | Caecal contents (25 g) | Ind, Cul |
| | Italy | Bonardi et al., 2003 | 0.367 | 0.290 | 0.444 | 150 | - | - | - | - | Caecal contents (10 g) | Ind, Cul |
| | | Cibin et al., 2007 | - | - | - | 1,557 | 0.607 | 0.514 | 0.700 | 107* | Mesenteric lymph nodes (5 g) | Ind, Cul |
| | Portugal | Vieira-Pinto et al., 2005 | 0.139 | 0.072 | 0.206 | 101 | - | - | - | - | Ileum contents (25 g) | Ind, Cul |
| | | | 0.188 | 0.112 | 0.264 | 101 | - | - | - | - | Ileocolic lymph nodes (25 g) | Ind, Cul |
| | | | 0.129 | 0.064 | 0.194 | 101 | - | - | - | - | Mandibular lymph nodes (10 g) | Ind, Cul |
| | | | 0.099 | 0.041 | 0.157 | 101 | - | - | - | - | Tonsils (10 g) | Ind, Cul |
| | United-Kingdom | Davies et al., 2003 | 0.243 | 0.202 | 0.284 | 420 | 0.800 | 0.625 | 0.975 | 20 | Caecal contents (25 g) | Ind, Cul |
| | | Davies et al., 2004 | 0.230 | 0.214 | 0.246 | 2,509 | - | - | - | - | Caecal contents (25 g) | Ind, Cul |
| | | Mac Dowell et al., 2007 | 0.314 | 0.274 | 0.354 | 513 | - | - | - | - | Caecal contents (50 g) | Ind, Cul |
| | United-States | Carlson and Blaha, 2001 | 0.037 | 0.031 | 0.043 | 3,442 | 0.640 | 0.452 | 0.828 | 25 | Ileocaecal lymph nodes | Ind, Cul |
| Digestive carriage (prevalence in digestive contents or tonsils and lymph nodes) | | Hurd et al., 2004 | 0.018 | 0.002 | 0.034 | 281 | 0.333 | 0.000 | 0.710 | 6 | Caecal contents (30 ml) collected on farm | Ind, Cul |
| | | | 0.136 | 0.096 | 0.176 | 286 | 1.000 | 0.974 | 1.000 | 6 | Caecal contents (30 ml) collected at slaughterhouse | Ind, Cul |
| | | | 0.036 | 0.014 | 0.058 | 281 | 0.833 | 0.535 | 1.000 | 6 | Ileocaecal (5 g) and inguinal (10 g) lymph nodes collected on farm | Ind, Cul |

Table 6. Continued

| Shedding or carriage | Country | Reference | Individual or pool prevalence | | Pigs tested | Herd prevalence | | Herds tested | Type of material sampled | Type of analysis | | |
|------------------------|---------|--------------------------|-------------------------------|----------|-------------|-----------------|----------|--------------|--------------------------|------------------|---|-------------|
| | | | p | p 95% CI | | p | p 95% CI | | | | | |
| | | | | | | | | | | | Lower limit | Upper limit |
| | | | 0.091 | 0.058 | 0.124 | 286 | 0.833 | 0.535 | 1.000 | 6 | Ileo-caecal (5 g) and inguinal (10 g) lymph nodes collected at slaughterhouse | Ind, Cul |
| | | Bahnson et al., 2006a | - | - | - | 300 | 0.500 | 0.190 | 0.810 | 10 | Ileo-caecal lymph nodes (5 x 0.5 g) | Pool, Cul |
| | | Bahnson et al., 2006b | 0.174 | 0.150 | 0.198 | 942 | 0.635 | 0.516 | 0.754 | 63 | Caecal contents (20 g) | Ind, Cul |
| | | | 0.145 | 0.123 | 0.167 | 941 | 0.492 | 0.369 | 0.615 | 63 | Ileo-colic lymph nodes (10 g) | Ind, Cul |
| | | Bahnson et al., 2006c | 0.070** | 0.062 | 0.078 | 4,380 | 0.685 | 0.610 | 0.760 | 146 | Ileo-colic lymph nodes (5 x 4 g) | Pool, Cul |
| | | Bahnson et al., 2007 | 0.084** | 0.077 | 0.091 | 6,330 | - | - | - | 211 | Ileo-colic lymph nodes (10 g) | Pool, Cul |
| | | Rostagno et al., 2007 | 0.279 | 0.253 | 0.305 | 1,110 | - | - | - | 33 | Mesenteric lymph nodes | Ind, Cul |
| Serological prevalence | Canada | Rajić et al., 2007 | 0.547 | 0.518 | 0.576 | 1,110 | - | - | - | 33 | Caecal contents | Ind, Cul |
| | | | 0.132 | 0.119 | 0.145 | 2,700 | 0.833 | 0.756 | 0.910 | 90 | Blood collected at slaughterhouse | Ind, AD |
| | Denmark | Mousing et al., 1997 | 0.054 | 0.053 | 0.055 | 604,006 | 0.047 | 0.043 | 0.051 | 13,036 | Meat juice (40% OD cut-off) | Ind, AD |
| | | Christensen et al., 1999 | 0.283 | 0.274 | 0.292 | 9,654 | - | - | - | 1,248 | Meat juice (30% OD cut-off) | Ind, AD |
| | | Stegge et al., 2000 | - | - | - | 4,800 | 0.230 | 0.146 | 0.314 | 96 | Blood collected at slaughterhouse (40% OD cut-off) | Pool, AD |
| | | | - | - | - | - | 0.450 | 0.350 | 0.550 | 96 | Meat juice (30% OD cut-off) | Pool, AD |
| | | Benschop et al., 2008 | 0.082 | 0.082 | 0.082 | 6,768,845 | - | - | - | 22,344 | Meat juice (20% OD cut-off) | Ind, AD |

Table 6. Continued

| Shedding or carriage | Country | Reference | Individual or pool prevalence | | | Herd prevalence | | | Type of material sampled | Type of analysis | | | |
|---|----------------|---------------------------|-------------------------------|-------------|-------------|-----------------|-------------|-------------|--------------------------|------------------|---|-----------------------------|---------|
| | | | p | p 95% CI | | p | p 95% CI | | | | | | |
| | | | | Lower limit | Upper limit | | Lower limit | Upper limit | | | | | |
| Germany | | Czerny et al., 2001 | 0.016 | 0.012 | 0.020 | 3,048 | 0.231 | 0.116 | 0.346 | 52 | Meat juice (40% OD cut-off) | Ind, AD | |
| | | Steinbach et al., 2002 | 0.099 | 0.094 | 0.104 | 11,896 | 0.367 | 0.331 | 0.403 | 679 | Blood collected at slaughterhouse (30% OD cut-off) | Ind, AD | |
| Greece | | Nowak et al., 2007 | 0.070 | 0.044 | 0.096 | 383 | 0.188 | 0.053 | 0.323 | 32 | Meat juice (40% OD cut-off) | Ind, AD | |
| | | Leontides et al., 2003 | 0.156 | 0.143 | 0.169 | 2,950 | 0.880 | 0.797 | 0.963 | 59 | Blood collected at slaughterhouse and on farm (10% OD cut-off) | Ind, AD | |
| Spain | | Mejia et al., 2006 | - | - | - | - | 0.773 | 0.704 | 0.842 | 141 | Blood 'collected at slaughterhouse (25% OD cut-off) | Pool, AD | |
| The Netherlands | | Van der Wolf et al., 2001 | - | - | - | - | 0.890 | 0.857 | 0.923 | 355 | Blood (at least 40 samples per herd) collected at slaughterhouse (10% OD cut-off) | Pool, AD | |
| Denmark, Germany, Greece, The Netherlands | United-Kingdom | Lo Fo Wong et al., 2003 | 0.470 | 0.455 | 0.485 | 4,194 | - | - | - | 77 | Blood (10% OD cut-off) | Ind, AD | |
| | | Davies et al., 2003 | 0.253 | 0.212 | 0.294 | 430 | 0.850 | 0.694 | 1.000 | 20 | Blood (25% OD cut-off) | Ind, AD | |
| United-States | | Davies et al., 2004 | 0.432 | 0.385 | 0.479 | 421 | 0.900 | 0.769 | 1.000 | 20 | Meat juice (25% OD cut-off) | Ind, AD | |
| | | Mac Dowell et al., 2007 | 0.152 | 0.138 | 0.166 | 2,509 | - | - | - | - | - | Meat juice (40% OD cut-off) | Ind, AD |
| United-States | | Hurd et al., 2004 | 0.115 | 0.087 | 0.143 | 513 | - | - | - | - | - | Meat juice (25% OD cut-off) | Ind, AD |
| | | Farzan et al., 2006 | - | - | - | 557 | 0.833 | 0.535 | 1.000 | 6 | Meat juice (20% OD cut-off) | Pool, AD | |
| | | | - | - | - | 557 | 0.667 | 0.290 | 1.000 | 6 | Meat juice (40% OD cut-off) | Pool, AD | |
| | | | - | - | - | - | 0.950 | 0.902 | 0.998 | 80 | Blood (10% OD cut-off) | Pool, AD | |

P, apparent prevalence; Ind, individual analysis; Pool, pooled samples analysed; Cul, culture; Nb, culture with numbering; AD, antibody detection; OD, optical density; -, lack of data.

*Number of batches.

**Individual estimated prevalence from regression.

Table 7. Summary of risk factors for *Salmonella enterica* shedding on pig farms reported in 23 studies

| Risk factor of presence of <i>Salmonella enterica</i> | | OR [90%CI] | Reference |
|---|---|------------------|---|
| Biosecurity measures and equipment | Cleaning measures and 'empty and clean' period | 2.9 [1.2-6.7] | Beloeil et al., 2004a |
| | Hygiene and clothes | 2.6 [1.1-6.4] | Fablet et al., 2003a; Beloeil et al., 2004a |
| Infection through people or equipment | Disinfection of rooms (without preliminary cleaning) is associated with a higher serological prevalence | 1.4* [1.1-1.9] | Van der Wolf et al., 2001 |
| | Washing room without disinfection (risk factor concerning all enteric pathogens in swine) | 3.3* [1.1-9.7] | Pearce, 1999 |
| | Residual <i>Salmonella</i> contamination of the room before loading of the batch followed | 3.1 [1.4-7.1] | Beloeil et al., 2004a |
| | Duration of 'empty and clean' period lower than 6 days in farrowing room | 3.1* [1.7-5.5] | Beloeil et al., 2004a |
| | Duration of 'empty and clean' period lower than 7 days in post-weaning | 3.2 [1.3-8.2] | Fablet et al., 2003a |
| | Duration of 'empty and clean' period lower than 3 days in fattening room | 2.0* [1.1-3.5] | Beloeil et al., 2004a |
| | Detection of <i>Salmonella</i> on boots or environmental samples and/or lack of boot-dip at the entrance of the facilities | NE | Letellier et al., 1999b; Rajic et al., 2005 |
| | Lack of hand hygiene before tending to pigs; lack of toilet | 2.1* [1.2-3.8] | Beloeil et al., 2004a |
| | More than two humans at finisher daily | 11.1* [1.8-70.2] | Funk et al., 2001b |
| | Allowing visitors with same day contact to other herds | 1.5* [1.1-2.1] | Lo Fo Wong et al., 2004 |
| Floors | Sharing equipment | 4.8* [1.4-17.1] | Funk et al., 2001b |
| | Solid floors or straw on floors versus slatted floor | 2.2 [1.3-3.9] | Bahnson et al., 2007 |
| | Partially slatted floor versus fully slatted | NE [†] | Langvad et al., 2006 |
| | Pierced pen separation between batches or possibilities of snout contacts | 1.5 [1.4-1.6] | Rosset et al., 2006 |
| | No acidification of feed or water | NE [‡] | Hill et al., 2007 |
| | Use of dry or liquid feed in comparison with fermented liquid feed | 8.9* [5.0-15.9] | Nollet et al., 2004 |
| | Numerous studies have showed higher bacteriological or serological prevalences in pigs herds using dry feed versus herds using wet feed | 1.7 [1.1-2.6] | Lo Fo Wong et al., 2004 |
| | Serological prevalence is higher in pigs fed with pelleted ration versus wet or dry non-pelleted ration | 1.4* [1.3-1.6] | Rosset et al., 2006 |
| | Distribution of more than two kinds of feeds between post-weaning and fattening period | 5.0* [2.8-8.9] | Van der Wolf et al., 2001 |
| | Change in the feed diet during the follow-up | 1.1* [0.2-6.8] | Kranker et al., 2001 |
| Feed and watering | Pen separation | 3.2 [1.4-7.1] | Beloeil et al., 2004a |
| | Acidification or fermented liquid feed | 4.9 [1.9-12.7] | Bahnson et al., 2006b |
| Dry feed | Use of dry or liquid feed in comparison with fermented liquid feed | 4.1* [1.4-12.2] | Farzan et al., 2006 |
| | Numerous studies have showed higher bacteriological or serological prevalences in pigs herds using dry feed versus herds using wet feed | 4.2* [2.0-8.7] | Kranker et al., 2001 |
| Pelleted feed | Serological prevalence is higher in pigs fed with pelleted ration versus wet or dry non-pelleted ration | 12.5* [2.2-71.6] | Leontides et al., 2003 |
| | Distribution of more than two kinds of feeds between post-weaning and fattening period | 2.4* [1.5-3.7] | Lo Fo Wong et al., 2004 |
| No. feeds | Distribution of more than two kinds of feeds between post-weaning and fattening period | 2.1 [1.2-3.8] | Bahnson et al., 2007 |
| | Change in the feed diet during the follow-up | NE [§] | Fablet et al., 2003a |
| Drinker design | Bowl drinkers are associated with higher prevalence than nipple drinkers | 3.4 * [1.9-6.1] | Beloeil et al., 2004a |
| | Infection of sow herds is associated with a higher serological prevalence in finishers | 8.0 [3.4-19.0] | Bahnson et al., 2006b |
| Herd management | Infection of sow herds is associated with a higher serological prevalence in finishers | 3.2* [1.6-6.5] | Kranker et al., 2001 |

Table 7. Continued

| Risk factor of presence of <i>Salmonella enterica</i> | | OR [90%CI] | Reference |
|--|--|----------------------------|---|
| Herd size | Risk of salmonella shedding seems to be associated with a higher herd size | NE | Baggesen et al., 1996; Carstensen and Christensen, 1998 |
| Herd type | Post-weaning to fattening herds and fattening herds were more contaminated than farrow-to-finish herds | 2.0 [1.3–3.0] | Bahnson et al., 2007 |
| | Space allowance inferior to 0.75m ² per pig | 1.3* [1.0–1.7] | Kranker et al., 2001 |
| | Link between 10 kg gain of weight and <i>Salmonella</i> shedding | 1.6 [1.4–1.8] | Rossel et al., 2006 |
| Stocking density | Mixing batches during the fattening period | NE [‡] | Clough et al., 2007 |
| | Continuous production of pigs compared to all-in/all-out | 4.5* [1.3–15.7] | Funk et al., 2001b |
| Origin of pigs Other breedings and contacts with domestic species or wild animals | Recruitment of pigs from more than 3 different supplier herds | 1.2 [1.0–1.5] | Bahnson et al., 2007 |
| | Poultry breeding on the farm | 1.5 [1.4–1.6] | Rossel et al., 2006 |
| | Other domestic species at the site or indirect contacts with other herds | 3.7* [2.1–6.4] | Lo Fo Wong et al., 2004 |
| | Contact with rodents | 3.9* [1.4–10.5] | Farzan et al., 2006 |
| | Supplemental ration versus approved growth promoter or probiotic | 3.3 [1.8–6.0] | Lo Fo Wong et al., 2004 |
| Health management | Curative antibiotic treatment at the end of the fattening period | 1.2 [1.1–1.3] | Rossel et al., 2006 |
| | Preventive antibiotic treatment during fattening enhances serological prevalence | 4.7* [1.2–18.0] | Funk et al., 2001b |
| | Using tylosine as growth promoter at the end of the fattening period | NE | Langvad et al., 2006 |
| | Using chlortetracycline as growth promoter during the fattening period | NE | Le Moine et al., 1987; Letellier et al., 1999b |
| | Serological prevalence is higher in pigs fed with a chlortetracycline, procaine penicillin and sulphamethazine | NE [§] | Fablet et al., 2003b |
| | Supplemented ration versus approved growth promoter or probiotic | 1.5 [1.4–1.7] | Rossel et al., 2006 |
| | Supplemented ration versus approved growth promoter or probiotic | 1.6 [1.2–2.2] | Van der Wolf et al., 2001 |
| | Supplemented ration versus approved growth promoter or probiotic | 6.9 [2.8–17.1] | Funk et al., 2007 |
| | Supplemented ration versus approved growth promoter or probiotic | 4.1 [†] [2.1–8.1] | Leontides et al., 2003 |

Table 7. Continued

| Intercurrent diseases | Risk factor of presence of <i>Salmonella enterica</i> | OR [90%CI] | Reference |
|-----------------------|---|----------------|---------------------------|
| | Diarrhoea in growing pigs | NE | Møller et al., 1998 |
| | Infections by PRRSV (Porcine Reproductive and Respiratory Syndrome Virus) | 3.0 [1.3–6.7] | Beloëil et al., 2004a |
| | Infections by PRCV (Porcine Respiratory Coronavirus) | 6.9 [2.2–21.6] | Fablet et al., 2003a; b |
| | Infections by <i>Lawsonia intracellularis</i> | 2.1 [1.2–3.7] | Beloëil et al., 2004a |
| | Liver infestations by <i>Ascaris suum</i> with high level (>16%) of liver condemnation at slaughterhouse during meat inspection | 2.1 [1.2–3.8] | Van der Wolf et al., 2001 |

NE, not possible to estimate.

*Calculated OR from published data.

†Epidemiological link showed by molecular strains typing methods.

‡Risk factor shown by modelisation.

§Results obtained from multiple factors analysis.

A herd prevalence estimate for *Y. enterocolitica* shedding was 0.599 whereas an individual prevalence estimate was 0.194 (Table 3). On intestinal contents samples, individual and herd prevalence estimates were 0.165 and 0.141, respectively. Tonsil samples showed prevalence ranging from 0.147 to 0.625 with a prevalence estimate of 0.324 whereas prevalence reported from other lymph nodes were lower (0.038–0.052; three values) which shows the extent of tonsil contamination. Serological herd prevalence ranged from 0.640 to 1.000 and serological individual prevalence range from 0.541 to 0.875. Differences between serological and faecal bacteriological prevalence suggest an intermittent faecal shedding in pigs (Altrock et al., 2007).

Sources of infection

Gurtler et al. (2005) showed that no piglets ($n = 600$) shed *Y. enterocolitica* in faeces in the period from farrowing to post-weaning whereas 19.6% of the 491 fattening pigs shed the bacteria at the end of the fattening period. Pilon et al. (2000) showed that Pulsed-Field Gel Electrophoresis (PFGE) profiles of isolates from pig faecal samples and environmental samples were specific for each of the 16 positive herds studied, with no genomic link between strains isolated from neighbouring farms. Rodents and flies were not found positive in one study (Pilon et al., 2000). Moreover, only 3.4% of the 117 environmental samples (feed and drinking troughs, water taps, and boots) were found positive in the study carried out by Altrock et al. (2007). Only one study reported a statistically significant association between the presence of cats on farms and higher serological prevalence (Skjerve et al., 1998). Herd management seems to have an influence on *Y. enterocolitica* presence. This point was reported by Skjerve et al. (1998) who showed serological individual and herd prevalences of 0.350 and 0.531, respectively, among 179 farrow-to-finish herds, versus serological individual and herd prevalences of 0.660 and 0.860, respectively, among 86 fattening herds. The lack of contact between pigs from different origins in farrow-to-finish herds may explain such a result.

Risk factors for shedding and transmission

Risk factors for infection with *Y. enterocolitica* included herd type (fattening herds versus farrow-to-finish herds) and biosecurity measures (Table 8).

Summary of Risk Factors for Bacterial Hazards in Slaughter Pigs

The two main biosecurity measures involved with the presence of bacterial food-borne pathogens in herds were

Table 8. Prevalence of pathogenic *Yersinia enterocolitica* in finishing pigs reported in 14 studies in eight European and North-American countries

| Shedding or carriage | Country | References | Individual or pool prevalence | | | Herd prevalence | | | Type of material sampled | Type of analysis | | | |
|--|--|-------------------------|---------------------------------|----------------------|----------------------|-----------------|----------------------|----------------------|--------------------------|--------------------------------|---|---------------------------------|----------|
| | | | p | p 95% CI Lower limit | p 95% CI Upper limit | p | p 95% CI Lower limit | p 95% CI Upper limit | | | | | |
| Shedding (prevalence in faeces or rectal contents) | Canada | Pilon et al., 2000 | 0.128* | 0.107 | 0.149 | 1,010 | 0.800 | 0.625 | 0.975 | 20 | Pen swabs | Ind, Cul | |
| | Finland | Asplund et al., 1990 | 0.177 | 0.115 | 0.239 | 147 | 0.357 | 0.106 | 0.608 | 14 | Faeces collected on farms | Ind, Cul | |
| | Germany | Gürtler et al., 2005 | 0.196 | 0.161 | 0.231 | 491 | 0.500 | 0.010 | 0.990 | 4 | Faeces (5 g) collected on farm | Ind, Cul | |
| | | | 0.005 | 0.001 | 0.012 | 379 | 0.500 | 0.010 | 0.990 | 4 | Faeces (5 g) collected at slaughterhouse | Ind, Cul | |
| | | Altrock et al., 2007 | 0.084 | 0.066 | 0.102 | 900 | - | - | - | 30 | Faeces collected at slaughterhouse | Ind, Cul | |
| | Norway | Nesbakken et al., 2003 | 0.125 | 0.001 | 0.257 | 24 | 1.000 | 0.963 | 1.000 | 3 | Faeces (10 g) collected at slaughterhouse | Ind, Cul | |
| | Digestive carriage (prevalence in digestive contents or tonsils and lymph nodes collected at slaughterhouse) | United States | Bhaduri et al., 2005 | 0.124 | 0.112 | 0.136 | 2,793 | 0.532 | 0.421 | 0.643 | 77 | Faeces (1 g) collected on farms | Ind, Cul |
| | | | Bowman et al., 2007 | 0.107 | 0.084 | 0.130 | 718 | 0.875 | 0.645 | 1.000 | 8 | Rectal and pharyngeal swabs | Ind, Cul |
| | | Canada | Letellier et al., 1999a | 0.173 | 0.153 | 0.193 | 1,420 | 0.673 | 0.611 | 0.735 | 223 | Caecal contents (1g) | Ind, Cul |
| | | Finland | Asplund et al., 1990 | 0.364 | 0.321 | 0.407 | 481 | 0.708 | 0.579 | 0.837 | 48 | Tonsils | Ind, Cul |
| | | | Fredriksson-Ahomaa et al., 2000 | 0.330 | 0.262 | 0.398 | 185 | - | - | - | - | Tonsils (10 g) | Ind, Cul |
| | | Germany | Gürtler et al., 2005 | 0.384 | 0.335 | 0.433 | 372 | 1.000 | 0.968 | 1.000 | 4 | Tonsils | Ind, Cul |
| | | | Nowak et al., 2006 | 0.050 | 0.020 | 0.080 | 210 | 1.000 | 0.974 | 1.000 | 6 | Ileocaecal lymph nodes | Ind, Cul |
| | | Italy | Bonardi et al., 2003 | 0.290 | 0.229 | 0.351 | 210 | 1.000 | 0.974 | 1.000 | 6 | Tonsils | Ind, Cul |
| 0.020 | | | | 0.001 | 0.039 | 210 | 1.000 | 0.974 | 1.000 | 6 | Ileocaecal lymph nodes | Ind, Cul | |
| Latvia | | Terentjeva et al., 2007 | 0.147 | 0.090 | 0.204 | 150 | - | - | - | - | Tonsils (1 g) | Ind, Cul | |
| | 0.310 | | 0.223 | 0.397 | 108 | 1.000 | 0.974 | 1.000 | 6 | Tonsils | Ind, Cul | | |
| Norway | Nesbakken et al., 2003 | 0.042 | 0.002 | 0.082 | 97 | 0.333 | 0.001 | 0.866 | 3 | Submaxillary lymph nodes (5 g) | Ind, Cul | | |
| | | 0.625 | 0.431 | 0.819 | 24 | 1.000 | 0.963 | 1.000 | 3 | Tonsils (10 g) | Ind, Cul | | |
| Serological prevalence | United States | Funk et al., 1998 | 0.042 | 0.001 | 0.122 | 3,375 | 0.333 | 0.001 | 0.866 | 103 | Mesenteric nodes (5 g) | Ind, Cul | |
| | | | 0.042 | 0.001 | 0.122 | 3,375 | 0.333 | 0.001 | 0.866 | 103 | Stomachs (10 g) | Ind, Cul | |
| | Denmark | Skjerve et al., 1998 | 0.167 | 0.108 | 0.316 | 1,605 | 0.333 | 0.001 | 0.866 | 265 | Ileum contents (10 g) | Ind, AD | |
| | | | 0.125 | 0.001 | 0.257 | 900 | 0.667 | 0.134 | 1.000 | 30 | Caecum contents (10 g) | Ind, AD | |
| | Germany | Altrock et al., 2007 | 0.083 | 0.001 | 0.193 | 900 | 0.667 | 0.134 | 1.000 | 30 | Colon contents (10 g) | Ind, AD | |
| | | | 0.132 | 0.121 | 0.143 | 3,375 | 0.282 | 0.195 | 0.369 | 103 | Oro-pharyngeal swabs | Ind, AD | |
| | Norway | Nesbakken et al., 2003 | 0.541 | 0.517 | 0.565 | 1,605 | 0.638 | 0.580 | 0.696 | 265 | Blood samples | Ind, AD | |
| | | | 0.668 | 0.637 | 0.698 | 900 | 0.833 | 0.700 | 0.966 | 30 | Blood samples at slaughterhouse | Ind, AD | |
| | | | 0.875 | 0.743 | 1.000 | 24 | 1.000 | 0.963 | 1.000 | 3 | Blood samples collected at slaughterhouse | Ind, AD | |

P, apparent prevalence; Ind, individual analysis; Pool, pooled samples analysed; Cul, culture; AD, antibody detection; -, lack of data.

Table 9. Summary of risk factors of food-borne zoonotic hazards prevalence in pig herds

| Characteristic of pig herd | No. studies showing the risk factor of increase in presence of foodborne pathogens | | | | |
|---|--|-------------------------------|----------------------------|--------------------------------|--|
| | <i>Campylobacter</i> spp. | <i>Listeria monocytogenes</i> | <i>Salmonella enterica</i> | <i>Yersinia enterocolitica</i> | |
| Biosecurity measures | | | | | |
| Lack of cleaning after batches removal and/or default of duration of the 'empty and clean' period | 1 | 1 | 5 | - | |
| Lack of change rooms at the entrance to the facilities and/or lack of hand or clothes hygiene | - | 1 | 5 | - | |
| Contact with visitors or contaminated equipment | - | - | 2 | - | |
| Contact with domestic or wild animals (bird and rodents) | - | - | 4 | 1 | |
| Nature of floors (straw or partially slatted floor versus fully slatted floor) | - | - | 4 | 1 | |
| Feed and watering | | | | | |
| Wet feed | - | 1 | - | - | |
| Dry feed | - | - | 4 | - | |
| Pelleted feed | - | - | 3 | - | |
| High (basic) pH feed or water | - | - | 2 | - | |
| Contaminated feed or water | - | - | - | 1 | |
| Change of diet during the following | - | - | 1 | - | |
| Cleaning of pipelines used for wet feed and water | - | 1 | - | - | |
| Bowl drinkers | - | - | 1 | - | |
| Herd management | | | | | |
| Infection of sows | - | - | 2 | - | |
| High density of animals (<0.75 m ² per pig) | - | - | 1 | - | |
| Small herd size (<1000 pigs) | 1 | - | - | 1 | |
| Huge herd size (> 1000 pigs) | - | - | 3 | - | |
| Fattening herds (versus farrow-to-finish herds) | - | - | 2 | 1 | |
| Presence of other species breedings | - | - | 3 | 1 | |
| Batches mixing or contact between pens (continuous production or snout contacts) | 1 | - | 3 | 1 | |
| Health management | | | | | |
| Preventive or curative antibiotic treatment during the fattening period | - | - | 5 | - | |
| Preventive or curative anthelmintic treatment during the fattening period | 1 | - | - | - | |
| Intercurrent diseases (diarrhoea, Porcine Reproductive and Respiratory Syndrome Virus, Porcine Respiratory Coronavirus, <i>Lawsonia intracellularis</i> , <i>Ascaris suum</i>) | - | - | 7 | - | |

-; lack of data (i.e. risk factor for which no study was published).

lack of cleaning after batch removal and the absence of cloth-boot change rooms at entrances to the facilities (Table 9). Straw on floors was a reported risk factor for the presence of *Salm. enterica* and *Y. enterocolitica*. Whereas wet feed increased the risk of infection of pigs with *L. monocytogenes*, dry feed was a risk factor for *Salmonella*. Mixing pig batches, notably in fattening herds, increased the transmission of *Salmonella* and *Yersinia*. Whereas small herds (<1000 pigs) were more contaminated by thermophilic campylobacters and *Y. enterocolitica*, large herds were associated with higher prevalence of *Salmonella*. Antibiotic treatment during the fattening period seems to increase the risk of transmission of *Salmonella*.

These risk factors may be used for a risk-profiling approach of farms. For instance, herds with a lack of cleaning after batches removal could be considered as high risk herds for *Campylobacter*, *L. monocytogenes* and *Salm. enterica*, in opposition to herds for which cleaning after batches removal is systematically carried out. Besides, wet fed pigs herds may be considered as high-risk herds for *L. monocytogenes*, in opposition to dry fed pigs herds. Nevertheless, further studies are needed to complete and to explain some of these factors and to improve their use in a pre-harvest hazard control approach.

Discussion and Conclusion

Meat contamination by food-borne pathogens mainly occur: (i) on farms, with primary contamination of muscles and tissues, (ii) during slaughtering from digestive contents and/or digestive tract tissues of pigs themselves when the reservoir of hazards is digestive (Fosse and Magras, 2004). To strengthen working relationships between farm and slaughterhouse in a risk assessment approach to control food-borne zoonoses, new European Union regulations notably require 'food chain information'. The goal of this effective risk approach is to provide information that is meaningful, relevant and targeted to four high-risk pork-borne pathogens (EFSA-ECDC, 2007; Fosse et al., 2008a) faecal shedding and/or digestive carriage of finishing pigs, which are the primary products of this pork food chain. The primary objective of this review was to better map the knowledge base of prevalence and risk factor data of four high-risk food-borne pathogens in finishing pigs. Prevalence estimates are affected by the sampling strategy and diagnostic procedure (Davies et al., 2003; Sanchez et al., 2007). So to describe the between-study variation in pathogen prevalence and to establish prevalence distributions which could be used in risk assessment, a quantitative meta-analysis has been carried out.

A systematic literature search was conducted. Among 256 articles that met the inclusion criteria on CAB and Medline databases, 86 articles contained original data suitable for a quantitative meta-analysis performed on prevalence at the herd and finishing pig levels. Since serological herd-prevalence is partially linked with digestive carriage herd-prevalence (Christensen et al., 1999; Davies et al., 2003), these data were also included. Few data were available on *L. monocytogenes* in pigs (three studies). For thermophilic *Campylobacter* spp., *Salm. enterica* and *Y. enterocolitica*, 17, 46 and 14 papers reporting apparent prevalence and 1, 23 and 2 papers reporting risk factors were used, respectively. To our knowledge, this is the first time that such a review has been conducted. Even if such work may never be considered exhaustive, the authors felt that all the relevant literature was identified. Criteria used to exclude publications (notably language) could have partially biased results, even if scientific publications quoted on databases were mainly written in English. The assessment of quality of included studies was carried out by two abstractors who compared their results and had the same conclusions. Nevertheless, it could also be responsible for bias. Our results could thus only be considered as primary estimates of prevalence.

The second objective of this review was to identify significant risk factors for increase in food-borne zoonotic hazards prevalence in finishing pigs herds which may be used as food chain information in a farm to fork risk assessment approach. However, very few data were published for risk factors on *Campylobacter* spp. (Wehebrink et al., 2007), *L. monocytogenes* (Beloeil et al., 2003a; b) and *Y. enterocolitica* (Skjerve et al., 1998; Pilon et al., 2000) whereas risk factors for *Salmonella* have been studied in more detail (23 papers). Consequently, such a summarization may be considered a first qualitative approach to risk factor critical review. Nevertheless, its use in managing food-borne hazards in the pork food chain in a farm to fork approach may already be taken into account. Moreover, each hazard should be considered separately with a reasoned discussion of risk factors linked with its bacteriological characteristics (growth conditions, survival in a given environment, and ability for biofilm formation). However, when considering global risk factors (Table 9), the two main categories of risk factors are: (i) biosecurity measures with a lack or absence of external and internal measures preventing hazard transmission such as contact with other animals (Skjerve et al., 1998; Letellier et al., 1999b; Langvad et al., 2006) or contaminated feed and watering (Hurd et al., 2001; Beloeil et al., 2003b; Bahnson et al., 2006b); (ii) herd management practices with considerable transmission of hazards (mixing of batches, snout contact).

For *L. monocytogenes* very few data of prevalence were reported. Nevertheless, pigs infection seems very low. On the opposite, wide ranges of apparent prevalence were reported for *Salm. enterica*, *Campylobacter* spp. and *Y. enterocolitica*. Sanchez et al. (2007) have shown that the three most important factors influencing the apparent prevalence of *Salmonella* in pigs were diagnostic procedures, sampling design and countries. This review analysed three categories of prevalence estimates: pig shedding prevalence (bacteriological data from fresh faeces or rectal contents), pig carriage prevalence (from digestive tissues or contents), serological prevalence. Consequently, prevalence estimates are less biased by diagnostic procedures and sampling design and observed variations may be explained by particular sanitary situations. The Q parameter values showed that the heterogeneity of data used was not significant for *Campylobacter* and *Y. enterocolitica*. Such results suggested that *Campylobacter* and *Y. enterocolitica* pigs shedding and/or carriage could be independent of the country status or that herd management practices are not significantly different in European and North-American countries for this hazard.

Prevalence estimates highly range according to material sampled and analyses carried out (bacteriological or serological analyses). Serological individual prevalence summaries were systematically higher than bacteriological individual prevalence summaries except for *Salm. enterica*. For this hazard, we also showed that serological individual or herd prevalence estimates were highly dependent on the optical density cut-off. Serological analyses with high cut-off could conduct to underestimates of *Salmonella* infection in pigs.

For all hazards, individual prevalence estimates for pig carriage (samples collected at slaughterhouses) were higher than individual prevalence estimates for pig shedding (samples collected on farms or at slaughterhouses). Such results may be explained by two points: (i) sampling at slaughterhouses can be targeted to predilection sites for the presence of bacteria: lymph nodes – especially tonsils – for *Y. enterocolitica* (Tauxe et al., 1987), intestinal and caecal contents for *Salmonella* (Hurd et al., 2004; Sørensen et al., 2004; Bahnson et al., 2006b; Rostagno et al., 2007); (ii) the transfer of bacteria from digestive tissues to digestive tracts due to stress during transport or lairage at slaughterhouses and/or infection of pigs from herd to slaughterhouse (Fravalo et al., 1999). *Campylobacter* pig shedding and carriage prevalence were very high. This showed that this hazard is widespread all over the world. Thus, this pig digestive tract bacterium would be an interesting indicator of faecal contaminations during the slaughtering process (Laroche et al., 2007). *Salmonella enterica* and *Y. enterocolitica* are characterized by lower individual and herd prevalence.

To summarize, the application of good hygiene and biosecurity practices in herds, notably with respect to cleaning and disinfection procedures and high hygiene standard of clothes, may reduce the contamination pressure at slaughter. As a priority in biosecurity measures, limiting the mixing of pig batches is needed, as well as less antibiotic treatment. These measures can be taken to reduce the presence of food-borne hazards in the first step in the pork food chain, i.e. the farm, and thus to better protect consumers. Further studies are needed to characterize pig infection at herd level, notably for *L. monocytogenes* and to quantify the correlation between infection of pigs on farms and contamination of carcasses at slaughterhouses.

Acknowledgements

The authors thank the Directorate of Food Safety of the French Ministry of Agriculture for financial support, Geoffrey Trassart for his help in literature search and Jos Noordhuizen for the critical revision of the manuscript.

References

- Alter, T., F. Gaull, S. Kasimir, M. Gurtler, H. Mielke, M. Linnebur, and K. Fehlhaber, 2005: Prevalences and transmission routes of *Campylobacter* spp. strains within multiple pig farms. *Vet. Microbiol.* 108, 251–261.
- Altrock, A. V., A. L. Louis, U. Roesler, T. Alter, M. Beyerbach, L. Krienbrock, and K. H. Waldmann, 2007: Prevalence of *Campylobacter* spp. and *Yersinia enterocolitica* in fattening pig herds in Lower Saxony, Germany. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 101–104.
- Arnold, M. E., A. Cook, and R. Davies, 2006: A modelling approach to estimate the sensitivity of pooled faecal samples for isolation of *Salmonella* in pigs. *J. R. Soc. Interface* 2, 365–372.
- Asplund, K., V. Tuovinen, P. Veijalainen, and J. Hirn, 1990: The prevalence of *Yersinia enterocolitica* O:3 in Finnish pigs and pork. *Acta Vet. Scandinav.* 31, 39–43.
- Baggesen, D. L., H. C. Wegener, F. Bager, H. Stege, and J. Christensen, 1996: *Salmonella enterica* infections in Danish slaughter pigs. *Prev. Vet. Med.* 26, 201–213.
- Bahk, J., and E. H. Marth, 1990: Listeriosis and *Listeria monocytogenes*. In: Cliver, D. O. (ed), Food-Borne Diseases, pp. 247–257. Academic Press, San Diego.
- Bahnson, P. B., C. Snyder, and L. M. Omran, 2006a: *Salmonella enterica* in superficial cervical (prescapular) and ileocaecal lymph nodes of slaughtered pigs. *J. Food Prot.* 69, 925–927.
- Bahnson, P. B., P. J. Fedorka-Cray, S. R. Ladely, and N. E. Mateus-Pinilla, 2006b: Herd-level risk factors for *Salmonella*

- enterica* subsp. *enterica* in U.S. market pigs. *Prev. Vet. Med.* 76, 249–262.
- Bahnson, P. B., D. J. Damman, R. E. Isaacson, G. Y. Miller, R. M. Weigel, and H. F. Troutt, 2006c: Prevalence and serovars of *Salmonella enterica* isolated from ileocolic lymph nodes of market pigs reared in selected Midwest US pig herds. *J. Swine Health Prod.* 14, 182–188.
- Bahnson, P. B., H. F. Troutt, R. M. Weigel, G. Y. Miller, and R. E. Isaacson, 2007: Risk factors for the detection of *Salmonella* in ileocolic lymph nodes in US slaughtered. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork, Verona, Italy, pp. 73–76.
- Barber, D. A., P. B. Bahnson, R. Isaacson, C. J. Jones, and R. M. Weigel, 2002: Distribution of *Salmonella* in swine production ecosystems. *J. Food Prot.* 65, 1861–1865.
- Barker, I. K., and A. A. Van Dreumel, 1985: The Alimentary System. In: Jubb, K. V. F., P. C. Kennedy, and N. Palmer (eds), Pathology of Domestic Animals, Vol. 2, pp. 1–239. Academic Press, Orlando.
- Beloil, P.-A., C. Chauvin, M. T. Toquin, C. Fablet, Y. Le Notre, G. Salvat, F. Madec, and P. Fravallo, 2003a: *Listeria monocytogenes* infection of finishing pigs: an exploratory epidemiological survey in France. *Vet. Res.* 34, 737–748.
- Beloil, P.-A., P. Fravallo, C. Chauvin, C. Fablet, G. Salvat, and F. Madec, 2003b: *Listeria* spp. infection in piggeries: comparison of three sites of environmental swabbing for detection and risk factor hypothesis. *J. Vet. Med. Serie. B* 50, 155–160.
- Beloil, P.-A., C. Chauvin, K. Proux, F. Madec, P. Fravallo, and A. Alioum, 2004a: Risk factors for *Salmonella enterica* subsp. *enterica* shedding by market-age pigs in French farrow-to-finish herds. *Prev. Vet. Med.* 63, 103–120.
- Beloil, P.-A., C. Chauvin, K. Proux, F. Madec, P. Fravallo, and A. Alioum, 2004b: Impact of the *Salmonella* status of market-age pigs and the pre-slaughter process on *Salmonella* caecal infection at slaughter. *Vet. Res.* 35, 513–530.
- Benschop, J., M. L. Hazelton, M. A. Stevenson, J. Dahl, R. S. Morris, and N. P. French, 2008: Descriptive spatial epidemiology of subclinical *Salmonella* infection in finisher pig herds: application of a novel method of spatially adaptive smoothing. *Vet. Res.* 39, 02.
- Bhaduri, S., I. V. Wesley, and E. J. Bush, 2005: Prevalence of pathogenic *Yersinia enterocolitica* strains in pigs in the United States. *Appl. Env. Microbiol.* 71, 7117–7121.
- Biksi, I., M. Lorincz, B. Molnár, T. Kecskés, N. Takács, D. Mirt, A. Cizek, Z. Pejsak, G. P. Martineau, J. L. Sevin, and O. Szenci, 2007: Prevalence of selected enteropathogenic bacteria in Hungarian finishing pigs. *Acta Vet. Hung.* 55, 219–227.
- Blahe, T., 1999: Epidemiology and quality assurance application to food safety. *Prev. Med. Vet.* 39, 81–92.
- Boes, J., L. Nersting, E. M. Nielsen, S. Kranker, C. Enøe, H. C. Wachmann, and D. L. Baggesen, 2005: Prevalence and diversity of *Campylobacter jejuni* in pig herds on farms with and without cattle or poultry. *J. Food Prot.* 68, 722–727.
- Bonardi, S., F. Brindani, G. Plizzin, L. Lucidi, M. d’Incau, E. Liebana, and S. Morabito, 2003: Detection of *Salmonella* spp., *Yersinia enterocolitica* and verocytotoxin-producing *Escherichia coli* O157 in pigs at slaughter in Italy. *Int. J. Food Microbiol.* 85, 101–110.
- Botteldoorn, N., M. Heyndrickx, N. Rijpens, and L. Herman, 2001: Prevalence of *Salmonella*, *Campylobacter* and VTEC on pig farms. *Meded. Rijksuniv. Gent. Fak. Landbouwk. Toegep. Biol. Wet.* 66(3b), 373–380.
- Bouyer, J., 2000: Méthodes statistiques. Médecine – Biologie. ESTEM, Editions INSERM, Paris.
- Bouyer, J., D. Hémon, S. Cordier, F. Derriennic, I. Stücker, B. Stengel, and J. Clavel, 1995: Epidémiologie – Principes et méthodes quantitatives. Editions INSERM, Paris.
- Bowman, A. S., C. Glendening, T. E. Wittum, J. T. Lejeune, R. W. Stich, and J. A. Funk, 2007: Prevalence of *Yersinia enterocolitica* in different phases of production on pig farms. *J. Food Prot.* 70, 11–16.
- Buncic, S., 1991: The incidence of *Listeria monocytogenes* in slaughtered animals, in meat and in meat products in Yugoslavia. *Int. J. Food Microbiol.* 12, 173–180.
- Byrd, J. A., B. M. Hargis, D. J. Caldwell, R. H. Bailey, R. L. Herron, J. L. McReynolds, R. L. Brewer, R. C. Anderson, K. M. Bischoff, T. R. Callaway, and L. F. Kubena, 2001: Effect of lactic acid administration in the drinking water during preslaughter feed withdrawal on *Salmonella* and *Campylobacter* infection of broilers. *Poultry Sc.* 80, 278–283.
- Carlson, A. R., and T. Blaha, 2001: In-herd prevalence of *Salmonella* in 25 selected Minnesota pig farms. *J. Swine Health Prod.*, 9, 7–10.
- Carstensen, B., and J. Christensen, 1998: Herd size and sero-prevalence of *Salmonella enterica* in Danish pig herds: a random-effects model for register data. *Prev. Vet. Med.* 34, 191–203.
- Cereser, A., G. Capelli, M. Favretti, D. Marchesan, R. Marchesan, M. Marcali, K. Rossetto, and F. Furlan, 2007: Prevalence of food-borne pathogens in rural pigs and in derived cold pork meats – preliminary report. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 110–112.
- Christensen, J., D. L. Baggesen, V. Sørensen, and B. Svensmark, 1999: *Salmonella* level of swine herds based on serological examination of meat-juice samples and *Salmonella* occurrence measured by bacteriological follow-up. *Prev. Vet. Med.* 40, 277–292.
- Christensen, J., D. L. Baggesen, B. Nielsen, and H. Stryhn, 2002: Herd prevalence of *Salmonella* spp. in Danish pig herds after implementation of the Danish *Salmonella* Control Program with reference to a pre-implementation study. *Vet. Microbiol.* 88, 175–188.
- Cibin, V., M. Mancin, L. Barco, K. Antonello, P. Zavagnin, and A. Ricci, 2007: *Salmonella* monitoring in pigs in the Veneto Region of Italy: results of three monitoring

- campaigns from 2002 to 2006. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 113–116.
- Clough, H., J. Sanderson, P. Brown, A. Miller, and A. Cook, 2007: The role of routine data in understanding the geography and timing of *Salmonella* on UK pig farms. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 69–72.
- Collins, J. D., and P. G. Wall, 2004: Food safety and animal production systems: controlling zoonoses at farm level. *Rev. Sci. Tech. Off. Int. Epiz.* 23, 685–700.
- Craven, J. A., and D. B. Hurst, 1982: The effect of time in lairage on the frequency of *Salmonella* infection in slaughtered pigs. *J. Hygiene* 88, 107–111.
- Czerny, C. P., K. Osterkorn, G. Wittkowski, and M. Huber, 2001: Meat juice ELISA for determination of *Salmonella* incidence in slaughter pig herds in Bavaria. *Berl. Munch. Tierarztl. Wochenschr.* 114, 35–39.
- Davies, P., J. Funk, and W. E. M. Morrow, 1999: Faecal shedding of *Salmonella* by a cohort of finishing pigs in North Carolina. *J. Swine Health Prod.* 7, 231–234.
- Davies, R. H., P. J. Heath, S. M. Coxon, and A. R. Sayers, 2003: Evaluation of the use of pooled serum, pooled muscle tissue fluid (meat juice) and pooled faeces for monitoring pig herds for *Salmonella*. *J. Appl. Microbiol.* 95, 1016–1025.
- Davies, R. H., R. Dalziel, J. C. Gibbens, J. W. Wilesmith, J. M. B. Ryans, S. J. Evans, C. Byrne, G. A. Paiba, S. J. S. Pascoe, and C. J. Teale, 2004: National survey for *Salmonella* in pigs, cattle and sheep at slaughter in Great Britain (1999–2000). *J. Appl. Microbiol.* 96, 750–760.
- De Boer, E., and J. F. M. Nouws, 1991: Slaughter pigs and pork as a source of human pathogenic *Yersinia enterocolitica*. *Int. J. Food Microbiol.* 12, 375–378.
- Devine, R., 2003: Meat consumption trends in the world and the European Union. *INRA Productions Animals* 16, 325–327.
- Doyle, M. P., 1990: *Campylobacter jejuni*. In: Cliver, D. O. (ed), Food-Borne Diseases, pp. 217–223. Academic Press, San Diego.
- Doyle, M. P., and D. O. Cliver, 1990a: *Salmonella enterica*. In: Cliver, D. O. (ed), Food-Borne Diseases, pp. 185–204. Academic Press, San Diego.
- Doyle, M. P., and D. O. Cliver, 1990b: *Yersinia enterocolitica*. In: Cliver, D. O. (ed), Food-Borne Diseases, pp. 223–228. Academic Press, San Diego.
- Duggan, S. J., D. M. Predergast, N. Leonard, C. Mannion, F. Butler, S. Fanning, and G. Duffy, 2007: Tracking of *Salmonella* positive pigs from farm to fork in the Republic of Ireland. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 91–94.
- European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC) 2007: The community summary report on trends and sources of zoonoses, zoonotic agents, antimicrobial resistance and foodborne outbreaks in the European Union in 2006. *EFSA J.* 130, 1–310.
- Fablet, C., P.-A. Beloeil, P. Fravallo, J. P. Jolly, E. Eveno, Y. Hascoet, G. Salvat, and F. Madec, 2003a: Etude des circonstances associées à l'excrétion de *Salmonella enterica* par les porcs en croissance. *Journées de la Recherche Porcine* 35, 401–408.
- Fablet, C., P. Fravallo, J. P. Jolly, E. Eveno, F. Madec, and P.-A. Beloeil, 2003b: Recherche des facteurs de risque de l'excrétion de *Salmonella enterica* par les porcs en croissance. Enquête épidémiologique analytique en élevage naisseur-engraisseur. *Epidemiol. Santé Animale* 43, 61–73.
- Fablet, C., C. Robinault, J. P. Jolly, V. Dorenlor, F. Eono, E. Eveno, A. Labbé, F. Madec, and P. Fravallo, 2007: Study of *Salmonella* infection of pig slurry in France. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 121–125.
- Farzan, A., R. M. Friendship, C. E. Dewey, K. Warriner, C. Poppe, and K. Klotins, 2006: Prevalence of *Salmonella* spp. on Canadian pig farms using liquid or dry-feed. *Prev. Vet. Med.* 73, 241–254.
- Fosse, J., and C. Magras, 2004: Dangers biologiques et consommation des viandes. Lavoisier, Paris.
- Fosse, J., C. Magras, and H. Seegers, 2007: Quantification of the informative value of meat inspection to detect biological hazards for pork consumers in Europe. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 22–26.
- Fosse, J., H. Seegers, and C. Magras, 2008a: Food-borne zoonoses: a quantitative approach for a relative risk assessment applied to pig slaughtering in Europe. *Vet. Res.* 39(1), 01.
- Fosse, J., N. Oudot, A. Rossero, M. Laroche, M. Federighi, H. Seegers, and C. Magras, 2008b: Contamination de produits primaires porcins par *Campylobacter* spp., *Clostridium perfringens* et *Salmonella enterica*. *Journées de la Recherche Porcine* 40, 55–60.
- Fravallo, P., V. Rose, E. Eveno, G. Salvat, and F. Madec, 1999: Définition bactériologique du statut de porcs charcutiers vis-à-vis d'une infection pas *Salmonella*. *Journées de la Recherche Porcine* 31, 383–389.
- Fredriksson-Ahomaa, M., J. Björkroth, S. Hielm, and H. Korkeala, 2000: Prevalence and characterization of pathogenic *Yersinia enterocolitica* in pig tonsils from different slaughterhouses. *Food Microbiol.* 17, 93–101.
- Fredriksson-Ahomaa, M., A. Stolle, A. Siitonen, and H. Korkeala, 2006: Sporadic human *Yersinia enterocolitica* infections caused by bioserotype 4/O:3 originate mainly from pigs. *J. Med. Microbiol.* 26, 132–137.
- Friendship, R., C. Dewey, K. Warriner, C. Poppe, and K. Klotins, 2006: Prévalence of *Salmonella* spp. on Canadian pig farms using liquid or dry-feed. *Prev. Vet. Med.* 73, 241–254.

- Funk, J. A., H. F. Troutt, R. E. Isaacson, and C. P. Fossler, 1998: Prevalence of pathogenic *Yersinia enterocolitica* in groups of pig at slaughter. *J. Food Prot.* 61, 677–682.
- Funk, J. A., P. R. Davies, and P. A. Nichols, 2001a: Longitudinal study of *Salmonella enterica* in growing pigs reared in multi-site pig production systems. *Vet. Microbiol.* 83, 45–60.
- Funk, J. A., P. R. Davies, and W. Gebreyes, 2001b: Risk factors associated with *Salmonella enterica* prevalence in three-site pig production systems in North Carolina, USA. *Berl. Munch. Tierarztl. Wochenschr.* 114, 335–338.
- Funk, J., T. E. Wittum, H. T. Lejeune, P. J. Rajala-Schultz, A. Bowman, and A. Mack, 2007: Evaluation of stocking density and subtherapeutic chlortetracycline on *Salmonella enterica* subsp. *enterica* shedding in growing swine. *Vet. Microbiol.* 124, 202–208.
- Garcia-Feliz, C., J. A. Collazos, A. Carjaval, A. B. Vidal, A. Aladueña, R. Ramiro, M. de la Fuente, M. A. Echeita, and P. Rubio, 2007: *Salmonella enterica* infections in Spanish pig fattening units. *Zoonoses Pub. Health* 54, 294–300.
- Gebreyes, W. A., S. Thakur, and W. E. Morrow, 2005: *Campylobacter coli*: prevalence and antimicrobial resistance in antimicrobial-free (ABF) pig production systems. *J. Antimicrob. Chemother.* 56, 765–768.
- Gebreyes, W. A., S. Thakur, and W. E. Morrow, 2006: Comparison of prevalence, antimicrobial resistance, and occurrence of multidrug-resistant *Salmonella* in antimicrobial-free and conventional pig production. *J. Food Prot.* 69, 743–748.
- Gürtler, M., T. Alter, S. Kasimir, M. Linnebur, and K. Fehlhaber, 2005: Prevalence of *Yersinia enterocolitica* in fattening pigs. *J. Food Prot.* 68, 850–854.
- Hamilton, D. R., P. Gallas, L. Lyall, S. Lester, S. McOrist, S. C. Hathaway, and A. M. Pointon, 2002: Risk-based evaluation of postmortem inspection procedures for pigs in Australia. *Vet. Rec.* 151, 110–116.
- Harvey, R. B., C. R. Young, R. L. Ziprin, M. E. Hume, K. J. Genovese, R. C. Anderson, R. E. Droleskey, L. H. Stanker, and D. J. Nisbet, 1999: Prevalence of *Campylobacter* spp isolated from the intestinal tract of pigs raised in an integrated pig production system. *J. Am. Vet. Med. Assoc.* 215, 1601–1604.
- Hill, A. A., E. L. Snary, L. Alban, and A. J. C. Cook, 2007: An updated transmission model for *Salmonella* in grower-finisher pigs. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 10–13.
- Humphrey, T., and F. Jørgensen, 2006: Pathogens on meat and infection in animals – Establishing a relationship using *Campylobacter* and *Salmonella* as examples. *Meat Sc.* 74, 89–97.
- Hurd, H. S., J. K. Gailey, J. D. McKean, and M. H. Rostagno, 2001: Rapid infection in market-weight pig following exposure to a *Salmonella* Typhimurium-contaminated environment. *Am. J. Vet. Res.* 62, 1194–1197.
- Hurd, H. S., J. D. McKean, R. D. Griffith, and M. H. Rostagno, 2004: Estimation of the *Salmonella enterica* prevalence in finishing pig. *Epidemiol. Infect.* 132, 127–135.
- Iida, T., M. Kanzaki, A. Nakama, Y. Kokubo, T. Maruyama, and C. Kaneuchi, 1998: Detection of *Listeria monocytogenes* in humans, animals and foods. *J. Vet. Med. Sc.* 60, 1341–1343.
- ITP (Institut Technique du Porc), 2003: Le Porc par les chiffres. ITP, Paris.
- Jelsma, A., R. Lesuis, and E. Ronteltap, 2006: Final Report on the Data Analysis from the “Visual Inspection Pilot”. Food and Consumer Product Safety Authority, Hague, Netherlands, 36 p.
- Käsbohrer, A., D. Protz, R. Helmuth, K. Nöckler, T. Blaha, F. J. Conraths, and L. Geue, 2000: *Salmonella* in slaughter pigs of German origin: an epidemiological study. *Eur. J. Epidemiol.* 16, 141–146.
- Korsak, N., B. Jacob, B. Groven, G. Etienne, B. China, Y. Ghafir, and G. Daube, 2003: *Salmonella* infection of pigs and pork in an integrated pig production system. *J. Food Prot.* 66, 1126–1133.
- Kranker, S., J. Dahl, and A. Wingstrand, 2001: Bacteriological and serological examination and risk factor analysis of *Salmonella* occurrence in sow herds, including risk factors for high *Salmonella* seroprevalence in receiver finishing herds. *Berl. Munch. Tierarztl. Wochenschr.* 114, 350–352.
- Kranker, S., L. Alban, J. Boes, and J. Dahl, 2003: Longitudinal Study of *Salmonella enterica* Serotype Typhimurium infection in three Danish farrow-to-finish pig herds. *J. Clin. Microbiol.* 41, 2282–2288.
- Langvad, B., M. N. Skov, E. Rattenborg, J. E. Olsen, and D. L. Baggesen, 2006: Transmission routes of *Salmonella* Typhimurium DT 104 between 14 cattle and pig herds in Denmark demonstrated by molecular fingerprinting. *J. Appl. Microbiol.* 101, 883–890.
- Laroche, M., M. H. Desmots, B. Minvielle, A. Rossero, M. Federighi, C. Mircovich, and C. Magras, 2007: *Campylobacter coli* pulsed field gel electrophoresis genotypic diversity in pork food chain. *Zoon. Pub. Health* 54(Suppl. 1), 27.
- Le Moine, V., P. Vannier, and A. Jestin, 1987: Microbiological studies of wild rodents in farms as carriers of pig infectious agents. *Prev. Vet. Med.* 4, 399–408.
- Leblanc-Maridor, M., J. Conquerant, H. Seegers, and C. Belloc, 2008: Contamination des porcs et de leur environnement par *Campylobacter* en élevage naisseur-engraisseur. *Journées de la Recherche Porcine* 40, 13–18.
- Leontides, L. S., E. Grafanakis, and C. Genigeorgis, 2003: Factors associated with the serological prevalence of *Salmonella enterica* in Greek finishing pigherds. *Epidemiol. Infect.* 131, 599–606.
- Letellier, A., S. Messier, and S. Quessy, 1999a: Prevalence of *Salmonella* spp. and *Yersinia enterocolitica* in finishing pig at Canadian abattoirs. *J. Food Prot.* 62, 22–25.
- Letellier, A., S. Messier, J. Pare, J. Menard, and S. Quessy, 1999b: Distribution of *Salmonella* spp. in pig herds in Quebec. *Vet. Microbiol.* 67, 299–306.
- Lo Fo Wong, D. M., J. Dahl, P. J. Van der Wolf, A. Wingstrand, L. Leontides, and A. Von Altröck, 2003: Recovery of

- Salmonella enterica* from seropositive finishing pig herds. *Vet. Microbiol.* 97, 201–214.
- Lo Fo Wong, D. M., J. Dahl, H. Stege, P. J. Van der Wolf, L. Leontides, A. Von Altröck, and B. M. Thorberg, 2004: Herd-level risk factors for subclinical *Salmonella* infection in European finishing-pig herds. *Prev. Vet. Med.* 62, 253–266.
- Lurette, A., C. Belloc, S. Touzeau, T. Hoch, H. Seegers, and C. Fourichon, 2007: Modelling the prevalence of *Salmonella* carrier pigs at slaughtering age: influence of management systems and of the *Salmonella* status replacement gilts. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 86–90.
- Mac Dowell, S. W., R. Porter, R. Madden, B. Cooper, and S. D. Neill, 2007: *Salmonella* in slaughter pigs in Northern Ireland: prevalence and use of statistical modelling to investigate sample and abattoir effects. *Int. J. Food Microbiol.* 118, 116–125.
- Magras, C., N. Garrec, M. Laroche, A. Rossero, C. Mircovich, M.-H. Desmonts, and M. Federighi, 2004: Sources of *Campylobacter* sp. infection of piglets in farrowing units of farrow-to-finish farms: first results. In: Madec, F., and G. Clement (eds), Animal Production in Europe: the Way Forward in a Changing World. In-between Congress of the ISAH, pp. 409–410. Saint-Malo, France.
- Magras, C., M. Laroche, M. Lebigre, J. Fosse, M. H. Desmonts, and C. Mircovich, 2005: *Campylobacter* quantitative risk analysis in fattening pig slaughterhouses. In: Proceedings of the 5th Annual Scientific Conference of the European College of Veterinary Public Health, pp. 13–14. Glasgow, United Kingdom.
- Maunsell, B., and D. J. Bolton, 2004: Guidelines for Food Safety Management on Farms. The National Food Centre, Teagasc.
- Mejía, W., J. Casal, D. Zapata, G. J. Sánchez, M. Martín, and E. Mateu, 2006: Epidemiology of salmonella infections in pig units and antimicrobial susceptibility profiles of the strains of *Salmonella* species isolated. *Vet. Rec.* 159, 271–276.
- Merialdi, G., C. Tittarelli, M. Bonci, G. Barbieri, M. Casali, L. Franchi, G. Granito, S. Guerzoni, and M. Dottori, 2007: Longitudinal study of *Salmonella* infection in four Italian farrow-to-finish pig herds. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 82–85.
- Minvielle, B., C. Magras, M. Laroche, M. H. Desmonts, and C. Mircovich, 2007: *Campylobacter* in the pork food chain: a quantitative hazard analysis. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 145–148.
- Møller, K., T. K. Jensen, S. E. Jorsal, T. D. Leser, and B. Carstensen, 1998: Detection of *Lawsonia intracellularis*, *Serpulina hyodysenteriae*, weakly beta-haemolytic intestinal spirochaetes, *Salmonella enterica*, and haemolytic *Escherichia coli* from pig herds with and without diarrhoea among growing pigs. *Vet. Microbiol.* 62, 59–72.
- Mousing, J., P. T. Jensen, C. Halgaard, F. Bager, N. Feld, B. Nielsen, J.-P. Nielsen, and S. Bech-Nielsen, 1997: Nationwide *Salmonella enterica* surveillance and control in Danish slaughter swine herds. *Prev. Vet. Med.* 29, 247–261.
- Mulder, R. W. A. W., 1995: Impact of transport and related stresses on the incidence and extent of human pathogens in pigmeat and poultry. *J. Food Saf.* 15, 239–246.
- Nesbakken, T., K. Eckner, H. K. Høidal, and O. J. Røtterud, 2003: Occurrence of *Yersinia enterocolitica* and *Campylobacter* spp. in slaughter pigs and consequences for meat inspection, slaughtering, and dressing procedures. *Int. J. Food Microbiol.* 80, 231–240.
- Nollet, N., D. Maes, L. De Zutter, L. Duchateau, K. Houf, K. Huysmans, H. Imberechts, R. Geers, A. De Kruif, and J. Van Hoof, 2004: Risk factors for the herd-level bacteriologic prevalence of *Salmonella* in Belgian slaughter pigs. *Prev. Vet. Med.* 65, 63–75.
- Nollet, N., K. Houf, J. Dewulf, A. De Kruif, L. De Zutter, and D. Maes, 2005: *Salmonella* in sows: a longitudinal study in farrow-to-finish pig herds. *Vet. Res.* 36, 645–656.
- Nørnung, B., and S. Buncic, 2007: Microbial safety of meat in the European Union. *Meat Sc.* 78, 14–24.
- Nowak, B., T. Mueffling, K. Caspari, and J. Hartung, 2006: Validation for the detection of virulent *Yersinia enterocolitica* and their distribution in slaughter pigs from conventional and alternative housing systems. *Vet. Microbiol.* 117, 219–228.
- Nowak, B., T. Von Müffling, S. Chaunchom, and J. Hartung, 2007: *Salmonella* infection in pigs at slaughter and on the farm: a field study using an antibody ELISA test and a PCR technique. *Int. J. Food Microbiol.* 115, 259–267.
- Ono, K., H. Masaki, and Y. Tokumaru, 1995: Isolation of *Campylobacter* spp. from slaughtered cattle and pig on blood-free selective medium. *J. Vet. Med. Sc.* 57, 1085–1087.
- Payot, S., S. Dridi, M. Laroche, M. Federighi, and C. Magras, 2004: Prevalence and antimicrobial resistance of *Campylobacter coli* isolated from fattening pigs in France. *Vet. Microbiol.* 101, 91–99.
- Pearce, G. P., 1999: Epidemiology of enteric disease in grower-finisher pigs: a postal survey of pig producers in England. *Vet. Rec.* 144, 338–342.
- Pearson, A. D., M. Greenwood, T. D. Healing, D. Rollins, M. Shahamat, J. Donaldson, and R. R. Colwell, 1993: Colonization of broiler chickens by waterborne *Campylobacter jejuni*. *Appl. Env. Microbiol.* 59, 987–996.
- Petitti, D. B., 1994: Meta-Analysis, Decision Analysis and Cost-Effectiveness Analysis. Methods for Quantitative Synthesis in Medicine. Oxford University Press, Oxford.
- Pilon, J., R. Higgins, and S. Quessy, 2000: Epidemiological study of *Yersinia enterocolitica* in pig herds in Quebec. *Can. Vet. J.* 41, 383–387.

- Quirke, A. M., N. Leonard, G. Kelly, J. Egan, P. B. Lynch, T. Rowe, and P. J. Quinn, 2001: Prevalence of *Salmonella* serotypes of pig carcasses from high- and low-risk herds slaughtered in three abattoirs. *Berl. Munch. Tierarztl. Wochenschr.* 114, 360–362.
- Rajic, A., J. Keenlside, M. E. McFall, A. E. Deckert, A. C. Muckle, B. P. O'Connor, K. Manninen, C. E. Dewey, and S. A. McEwen, 2005: Longitudinal study of *Salmonella* species in 90 Alberta pig finishing farms. *Vet. Microbiol.* 105, 47–56.
- Rajić, A., E. Y. Chow, J. T. Wu, A. E. Deckert, R. Reid-Smith, K. Manninen, C. E. Dewey, M. Fleury, and S. A. McEwen, 2007: *Salmonella* infections in ninety Alberta pig finishing farms: serological prevalence, correlation between culture and serology, and risk factors for infection. *Food-borne Pathog. Dis.* 4, 169–177.
- Rossel, R., J. Rouillier, P.-A. Beloeil, C. Chauvin, F. Basta, J. P. Crabos, and S. Theau-Audin, 2006: *Salmonella* en élevage de porcs du Sud-Ouest de la France : séroprévalence en fin d'engraissement et facteurs de risque associés. *Journées de la Recherche Porcine* 38, 371–378.
- Rostagno, M. H., H. S. Hurd, and J. D. Mc Kean, 2007: *Salmonella enterica* prevalence and serotype distribution in pig at slaughter. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 153–155.
- Rowe, T. A., F. C. Leonard, G. Kelly, P. B. Lynch, J. Egan, A. M. Quirke, and P. J. Quinn, 2003: *Salmonella* serotypes present on a sample of Irish pig farms. *Vet. Rec.* 153, 453–456.
- Royer, E., G. Moundy, J. Albar, and G. P. Martineau, 2004: Analyse descriptive du degré d'hygiène microbiologique de la machine à soupe dans neuf élevages porcins; influence des différents maillons du circuit. *Revue Med. Vet.* 155, 609–618.
- Sanchez, J., I. R. Dohoo, J. Christensen, and A. Rajic, 2007: Factors influencing the prevalence of *Salmonella* spp. in swine farms: a meta-analysis approach. *Prev. Vet. Med.* 81, 148–177.
- Schruff, C., and T. Blaha, 2004: A decision model for the risk-based meat inspection. In: Madec, F., and G. Clement (eds), *Animal Production in Europe: the Way Forward in a Changing World*. In-between Congress of the ISAH, pp. 477–478. Saint-Malo, France.
- Schuppers, M. E., R. Stephan, U. Ledergerber, J. Danuser, B. Bissig-Choisat, K. D. Stärk, and G. Regula, 2005: Clinical herd health, farm management and antimicrobial resistance in *Campylobacter coli* on finishing pig farms in Switzerland. *Prev. Vet. Med.* 69, 189–202.
- Simonet, M., and M. Catteau, 2005: *Yersinia enterocolitica*. In: Federighi, M. (ed), *Bactériologie alimentaire*, pp. 173–188. Economica, Paris.
- Skjerve, E., B. Lium, B. Nielsen, and T. Nesbakken, 1998: Control of *Yersinia enterocolitica* in pigs at herd level. *Int. J. Food Microbiol.* 45, 195–203.
- Skovgaard, N., 1990: The impact of the prevalence of *Listeria monocytogenes* in the environment on meat and milk hygiene. *Microbiol. Alim. Nutrit.* 8, 15–20.
- Skovgaard, N., and B. Nørrung, 1989: The incidence of *Listeria* spp. in faeces of Danish pigs and in minced pork meat. *Int. J. Food Microbiol.* 8, 59–63.
- Sørensen, L. L., L. Alban, B. Nielsen, and J. Dahl, 2004: The correlation between *Salmonella* serology and isolation of *Salmonella* in Danish pigs at slaughter. *Vet. Microbiol.* 101, 131–141.
- Stanier, R. Y., J. L. Ingraham, M. L. Wheelis, and P. R. Painter, 1986: *The Microbial World*, 5th edn. Prentice-Hall, New Jersey.
- Stege, H., J. Christensen, J. P. Nielsen, D. L. Baggesen, C. Enøe, and P. Willeberg, 2000: Prevalence of subclinical *Salmonella enterica* infection in Danish finishing pig herds. *Prev. Vet. Med.* 44, 175–188.
- Steinbach, G., T. Blaha, and U. Methner, 2002: Estimating the prevalence of *Salmonella* spp. in pig herds - influence of sensitivity and specificity of *Salmonella* detection. *J. Vet. Med. B* 49, 438–444.
- Steinhausserova, I., M. Nebola, and M. Mikulicova, 2005: Prevalence of thermophilic *Campylobacter* spp. in slaughtered pigs in the Czech Republic, 2001–2003. *Vet. Med. Czech* 50, 171–174.
- Tauxe, R. V., J. Vandepitte, G. Wauters, S. M. Martin, V. Goossens, P. De Mol, R. Van Noyen, and G. Thiers, 1987: *Yersinia enterocolitica* infections and pork: the missing link. *Lancet* 8542, 1129–1132.
- Terentjeva, M., A. Berzins, and E. Liepins, 2007: A pilot study of *Yersinia enterocolitica* and *Yersinia pseudotuberculosis* in Latvian pigs at slaughtering. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 163–165.
- Van der Wolf, P. J., W. B. Wolbers, A. R. W. Elbers, H. M. J. F. Van der Heijden, J. M. C. C. Koppen, W. A. Hunneman, F. W. Van Schie, and M. J. M. Tielen, 2001: Herd level husbandry factors associated with a serological *Salmonella* prevalence in finishing pig herds in the Netherlands. *Vet. Microbiol.* 78, 205–219.
- Varela, N. P., R. Friendship, and C. Dewey, 2007a: Prevalence of resistance to 11 antimicrobials among *Campylobacter coli* isolated from pigs on 80 grower-finisher farms in Ontario. *Can. J. Vet. Res.* 71, 189–194.
- Varela, N. P., R. M. Friendship, and C. E. Dewey, 2007b: Prevalence of *Campylobacter* spp. isolated from grower-finisher pigs in Ontario. *Can. Vet. J.* 48, 515–517.
- Vieira-Pinto, M., P. Temudo, and C. Martins, 2005: Occurrence of salmonella in the ileum, ileocolic lymph nodes, tonsils, mandibular lymph nodes and carcasses of pigs slaughtered for consumption. *J. Vet. Med. B* 52, 476–481.
- Warris, P. D., 1992: Animal welfare. Handling animals before slaughter and the consequences for welfare and product quality. *Meat Focus Int.* 1, 135–138.

- Wehebrink, T., N. Kemper, E. Beilage, and J. Krieter, 2007: Carry-over risks in fattening units for *Campylobacter* spp. In: Proceedings of the 7th International Symposium on the Epidemiology and Control of Food-borne Pathogens in Pork. Verona, Italy, pp. 173–176.
- Weijtens, M. J. B. M., P. G. H. Bijker, J. Van der Plas, H. A. P. Urlings, and M. H. Biesheuvel, 1993: Prevalence of campylobacter in pigs during fattening: an epidemiological study. *Vet. Quarterly* 15, 138–143.
- Weijtens, M. J. B. M., J. Van der Plas, P. G. H. Bijker, H. A. P. Urlings, D. Koster, J. G. Van Logtestijn, and J. H. J. Huis-in't Veld, 1997: The transmission of campylobacter in piggeries: an epidemiological study. *J. Appl. Microbiol.* 83, 693–698.
- Weijtens, M. J. B. M., R. D. Reinders, H. A. P. Urlings, and J. Van der Plas, 1999: *Campylobacter* infections in fattening pigs: excretion pattern and genetic diversity. *J. Appl. Microbiol.* 86, 63–70.
- Weijtens, M. J. B. M., H. A. P. Urlings, and J. Van der Plas, 2000: Establishing a campylobacter-free pig population through a top-down approach. *Lett. Appl. Microbiol.* 30, 479–484.
- Yokoyama, E., T. Saitoh, S. Maruyama, and Y. Katsube, 2005: The marked increase of *Listeria monocytogenes* isolation from contents of pig cecum. *Comparative Immunol. Microbiol. Infect. Dis.* 28, 259–268.