Salmonella contamination: a significant challenge to the global marketing of animal food products

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Summary
Salmonellosis is the most common food-borne bacterial disease in the world. *Salmonella* is a significant pathogen for food-producing animals and these animals are the primary source of salmonellosis. It is estimated that herd prevalence varies between 0% and 90%, depending on the animal species and region. The pathogen is spread by trade in animals and non-heated animal food products. The emergence of strains that are resistant to antimicrobials, often as a result of antimicrobial usage in animals, is a public health hazard of great concern. It is increasingly accepted that the prevalence of *Salmonella* in animal production must be decreased and, in the European Union, plans to achieve this are currently being implemented. In this paper, the authors propose various risk mitigation strategies. Successful control must focus on a range of preventive actions because there is no simple 'silver bullet' solution to reduce *Salmonella* contamination. The authors conclude that the key to controlling *Salmonella* is to follow the general rules that have been successfully applied to other infectious diseases.

Keywords
Animal products – Antimicrobial resistance – Control – Disease – Epidemiology – Monitoring – Pre-harvest control – Risk mitigation – Salmonella – Salmonella contamination – Salmonella pathogenicity island – Salmonellosis – Virulence.

Introduction

In most parts of the world, countries have seen dramatic and continuous increases in human outbreaks of salmonellosis, caused by infections in animals. In 2004, in the European Union (EU) alone, 192,703 human cases of salmonellosis were reported (17). These and similar data from other countries almost certainly underestimate the magnitude of the problem, as many cases of salmonellosis are not reported. Often, the infected person does not visit a doctor, or no specimen is obtained for laboratory tests or laboratory findings are not reported. Taking into account this degree of under-reporting, the Centers for Disease Control estimate the annual number of non-typhoidal salmonellosis cases in the United States of America (USA) to be approximately 1.4 million (41).

In addition to human health implications, *Salmonella* is a pathogen of significant importance in worldwide animal production and the emergence of antibiotic-resistant strains, due principally to the therapeutic use of antimicrobials in animals, is a further threat to human and animal health. Increasing attention has been focused on the prevention and control of *Salmonella* in animal production, as this is the main source of outbreaks in humans (19, 66, 75). The need for global co-operation in controlling salmonellosis was emphasised at an early stage by the World Health Organization (WHO) (8). This is readily understandable since *Salmonella* infections are also

spread through international trade in animal feed, live animals and food. The control of *Salmonella* is thus an urgent challenge confronted by Veterinary Services and producers as they seek to produce safe foods of animal origin. A 'stable-to-the-table' approach is needed to implement stringent disease control measures. In this paper, the authors examine preventive measures at the pre-harvest level.

Salmonella

Nomenclature/taxonomy

The genus *Salmonella* belongs to the family Enterobacteriaceae. *Salmonellae* are facultative anaerobic, Gram-negative, oxidase-negative, rod-shaped bacteria. The genus *Salmonella* consists of two species, *Salmonella enterica* and *S. bongori*. *Salmonella enterica* is further divided into six subspecies:

– *S. enterica* subsp. *enterica*

– *S. enterica* subsp. *salamae*

– *S. enterica* subsp. *arizonae*

– *S. enterica* subsp. *diarizonae*

– *S. enterica* subsp. *houtenae*

– *S. enterica* subsp. *indica.*

More than 2,400 serovars are known. Serovars that are frequently isolated in human or veterinary medicine have historically been given names denoting syndrome (e.g. *S.* Typhi), host-specificity (e.g. *S.* Choleraesuis) or the geographical origin of the first isolation of a new serovar (e.g. *S.* Dublin).

Salmonellae cause disease in both humans and animals. The serovar *S.* Typhi and most *S.* Paratyphi strains (A, B and C), which cause serious systemic infections in humans, are specific human pathogens. These pathogens have no animal reservoir and so are not dealt with in this paper. Instead, the authors focus on the remaining serovars, usually known as the 'zoonotic *Salmonella* spp.', which cause so-called non-typhoidal salmonellosis in humans and sometimes also in animals.

Virulence

Understanding the mechanisms behind the survival of *Salmonella* bacteria, as they invade an exposed animal, and their ability to cause disease would enable researchers to prevent much of the suffering and economic losses caused by this pathogen. However, despite substantial research efforts, progress has been limited. The current knowledge may be summarised as follows.

Following oral uptake, *Salmonella* is successively exposed to:

a) low pH in the stomach

b) the strong antimicrobial effect of bile

c) decreasing oxygen supply

d) normal gut flora and metabolites

e) intestinal peristalsis

f) cationic antimicrobial peptides present on the surface of epithelial cells (50).

These encounters with stressful environments induce the expression of a number of genes whose products are essential for *Salmonella* to invade the intestinal epithelium and infect the host.

The ability to cause disease relies on several virulence determinants. Some of these may be seen as virulence determinants in the broad sense, including genes involved in nutrient biosynthesis/uptake, stress response (both in and outside the host) and repair of cell damage. These genes may be considered 'housekeeping' genes and are present in other closely related bacteria, such as *Escherichia coli* (5).

Another group of virulence genes specific for the genus *Salmonella* encode adaptations to overcome host defence mechanisms and may therefore be called true virulence determinants.

The expression of both groups of virulence genes is regulated in response to environmental signals in the host. The regulatory genes mediating this control may also be considered virulence determinants (5).

The genetic control of *Salmonella* virulence is not fully known. However, both plasmid and chromosomal genes are involved. Many of the virulence genes of *S. enterica* are located on pathogenicity islands of the chromosomes, referred to as '*Salmonella* pathogenicity islands' (SPI). These genes are believed to have been acquired by *Salmonella* from other bacterial species through horizontal gene transfer (62). They include functions such as host cell invasion and intracellular pathogenesis. Thus far, 12 different SPI have been described. The roles of some SPI in the pathogenesis of *Salmonella* spp. are well described but the function in virulence of many genes within SPI is not yet understood (27).

At least six serovars of *Salmonella* (Abortusovis, Choleraesuis, Dublin, Enteritidis, Gallinarum/Pullorum and Typhimurium) harbour a virulence plasmid (although not all isolates of these serovars do). These plasmids vary

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in size among the serovars. All these plasmids contain the *Salmonella* plasmid virulence (spv) locus. This locus harbours five genes designated spvRABCD (62). The first gene spvR encodes an activator of spvABCD, but the exact function of the encoded proteins is not fully known. These genes are induced by growth restriction, reduced nutrient supply or lowered pH and are involved in intra-macrophage survival of *Salmonella* (51).

Other virulence factors of *Salmonella* include the production of endotoxins and exotoxins, and the presence of fimbriae and flagellae. The role of these factors in the pathogenesis of *Salmonella* spp. is not fully established (62).

Salmonella infections

Salmonella infections in humans

Non-typhoid salmonellosis in humans is usually manifested as a localised enterocolitis. The incubation period ranges from five hours (h) to seven days, but clinical signs usually begin 12 h to 36 h after ingestion of a contaminated food. Shorter incubation periods are generally associated with either higher doses of the pathogen or highly susceptible people. Clinical signs include diarrhoea, nausea, abdominal pain, mild fever and chills. The diarrhoea varies from a few thin vegetable-soup-like stools to massive evacuations with accompanying dehydration. Vomiting, prostration, anorexia, headache and malaise may also occur. The syndrome usually lasts for two to seven days. Systemic infections sometimes occur, and usually involve the very young, the elderly or the immuno-compromised. A fatal outcome is rare. The excreta of infected patients contain large numbers of *Salmonella* spp. at the onset of illness. Those numbers decrease with the passing of time. Some patients become carriers, and some are still excreting *Salmonella* spp. after three months. Non-typhoid salmonellosis can later give rise to chronic diseases, including localised infections in specific tissues or organs and reactive arthritis, as well as neurological and neuromuscular illnesses. Subclinical infections and/or carriers also occur and investigations have found that 7% to 66% of infected humans are subclinical carriers (2).

Salmonella infections in animals

As with humans, *Salmonella*-infected animals may or may not develop disease. Those serovars that were initially observed to cause disease were found to be adapted to specific animal species, that is:

– *S.* Abortus ovis (sheep)
– *S.* Cholerae suis (pigs)
– *S.* Gallinarum (poultry)
– *S.* Abortus equi (horses)
– *S.* Dublin (cattle).

These serovars cause disease in the species to which they are adapted and are considered less pathogenic to people. However, when humans become infected, the same serovars often cause severe septicaemia (1, 54). These host-adapted serovars primarily cause abortions or severe gastroenteritis in their animal hosts.

A group of more frequently isolated serovars, such as *S.* Typhimurium, *S.* Enteritidis, *S.* Hadar and *S.* Infantis (among others), readily affect both humans and animals. In food animals, these serovars manifest themselves clinically through per-acute septicaemia, acute enteritis or chronic enteritis. In the subclinical form of the disease, the animal may either have a latent infection or become a temporary or persistent carrier (47).

The remaining, less frequently isolated serovars can colonise animals, usually without significant clinical signs, but they are all considered capable of causing gastro-intestinal infection of varying severity in humans.

In summary, in most food animal species, *Salmonellae* usually establish a clinically inapparent infection of variable duration, which is significant as a potential zoonosis. However, under various stress conditions, serovars that are usually non-pathogenic may also cause disease in food animal species.

No data are available to give the true prevalence of *Salmonella* in animal production or to provide true comparisons between countries. Existing data indicate that the herd prevalence, depending on animal species and region, may vary between 0% and 90% (in swine, cattle and poultry) (10, 11, 17, 56). Interestingly, Sweden, Finland and Norway have achieved virtually *Salmonella*-free animal production as the result of an intervention strategy, implemented some time ago, which proposed zero tolerance for *Salmonella* (17).

Serovars involved in human illness

Any serovar is considered capable of causing gastro-intestinal illness of varying severity in humans. In a global survey covering the years 1990 and 1995, *S.* Enteritidis and *S.* Typhimurium were the two most frequently isolated serovars among human isolates (29). These serovars were also the most frequently found in human outbreaks of salmonellosis in Europe in the period 1993 to 1998, being responsible for 77.1% of the recorded outbreaks and occurring in a ratio of approximatively 3:1 (77). In 2004, *S.* Enteritidis and S. Typhimurium were still the

most frequently reported serovars, accounting for 76% and 14%, respectively, of human isolates reported in the EU (17).

However, the current situation could easily change, as exemplified when an apparently new virulent strain of *S.* Enteritidis appeared in the 1980s, with the ability to infect the eggs of poultry. This resulted in a pandemic spread, combined with severe outbreaks in poultry but also in humans, with contaminated eggs and egg products being the principal vehicle (30). Similarly, the spread of the multi-antibiotic-resistant strain of *S.* Typhimurium (see below) demonstrated that dynamic spread of certain strains of *Salmonella* can easily occur. In particular, the pandemic spread of *S.* Enteritidis prompted a more active approach to the control of *Salmonella* (48).

Epidemiology

Animals infected after exposure to infected animals, feed or environmental conditions excrete *Salmonella* bacteria by faecal shedding. Faecal/intestinal contamination of carcasses is the principal source of human food-borne infections. The exception is when *Salmonella* is directly transmitted into the food product, for example, *S.* Enteritidis into eggs and sometimes other *Salmonella* serovars into milk. Humans excrete the microbe as animals do. *Salmonella* bacteria can survive for long periods in the environment, although in general no significant multiplication occurs. *Salmonella* infections in wild fauna, such as rodents, are usually secondary to the infection of farm animals, even though infection cycles may continue independently of any continuous input of *Salmonella* bacteria from farm animals, as described by Henzler and Opitz (28). In a review on the survival of *Salmonella* in the environment, Murray (43) concludes that control of *Salmonella* must start with a significant decrease in the number of organisms that are discharged into the environment. Animal and human faecal contamination of water and soil is also part of the epidemiological cycle and can contaminate, for example, vegetables, which then also become a source of food-borne human infections.

Animal sources of food-borne salmonellosis

An EU scientific committee concluded that the food categories that possibly pose the greatest hazard to public health include:

– raw meat and some meat products intended to be eaten raw

– raw or undercooked poultry meat products

– eggs and products containing raw eggs

– unpasteurised milk and some milk products.

Sprouted seeds, unpasteurised fruit juices and home-made mayonnaise are also of concern (54).

More correctly estimating the contributions of various food products to human outbreaks of *Salmonella* would require more detailed data. Situations are likely to vary between countries, according to different levels of *Salmonella* contamination and patterns of consumption. Two examples are available.

In the Netherlands, the estimated contributions of travel, farm animals and various animal products towards human salmonellosis are presented in the 2003 annual report of the Netherlands National Institute for Public Health and the Environment. Using typing data of *Salmonella* spp. isolates from laboratory surveillance, researchers estimated which fractions of human salmonellosis cases were attributable to which category of farm animals and their products, as well as which fraction was of unknown origin, including the possible cause of travel (Fig. 1). In 2003, the assessed total number of human salmonellosis cases amounted to 50,000 (308 cases per 100,000 head of population).

The estimated mean number of human cases in Denmark (per 100,000 inhabitants) that could be attributed to various sources is presented in Figure 2.

Transmission through trade and travelling

Salmonella is spread by the trade of live animals within and between countries. In Europe, the spread of infection with *S.* Typhimurium is typically seen as a result of trade in calves (7), and by parent and grandparent flocks in poultry production (45). Trade in contaminated animal feed products has also significantly contributed to the spread of *Salmonella* (59, 66), and several large outbreaks in humans have been traced back to contaminated animal feed (12). However, *Salmonella* is also spread by non-heat-treated animal products. In Sweden, in the 1950s, 500 people were reported to have been infected by *S.* Montevideo from meat imported from South America (55). Moreover, recent data from Denmark estimate the contribution from imported non-heat-treated meat (duck, turkey, chicken, beef and pork) to human cases of salmonellosis to be between 13.8% and 26.8% (Fig. 2).

Many countries have trade restrictions for *Salmonella* and trade between countries has often been interrupted by *Salmonella*-contaminated consignments (40). There have also been numerous alerts concerning *Salmonella*-contaminated meat, meat products and poultry notified through the rapid alert system for food and feed (RASFF) (49).

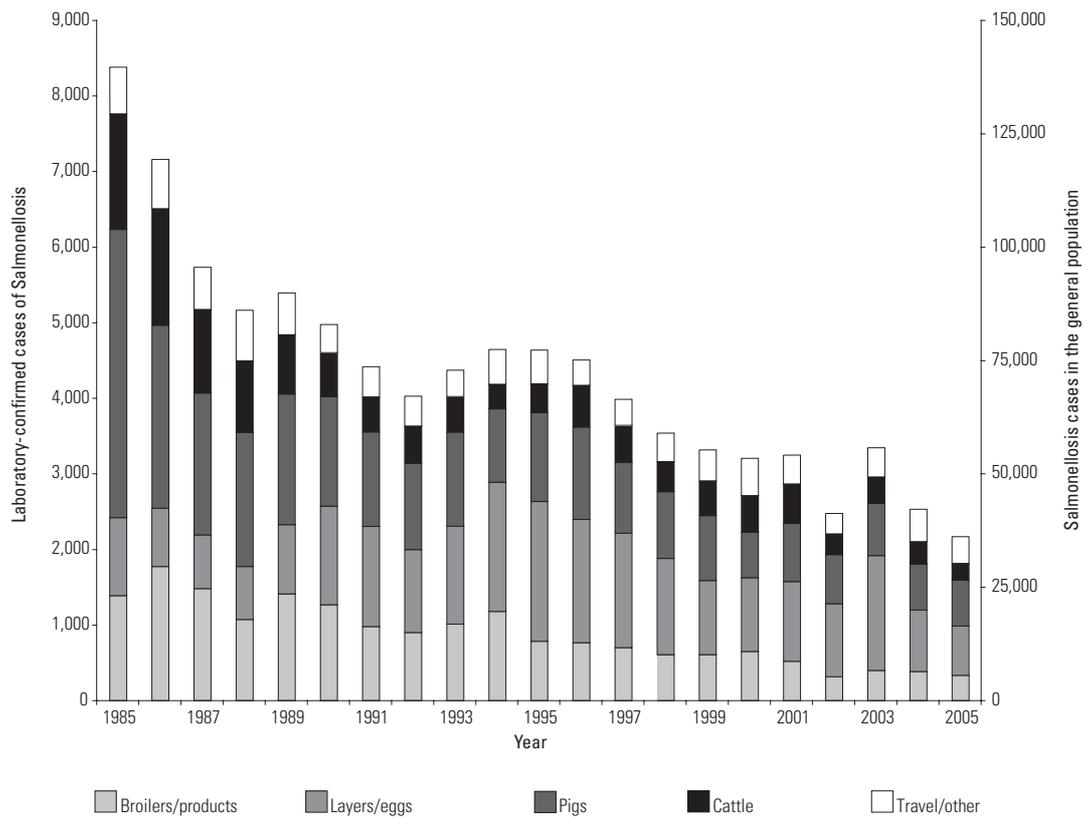*Salmonella* is additionally spread between countries by humans as a result of food-borne infections acquired

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Fig. 1
Estimated contributions of travel and farm animals and their products to laboratory-confirmed human salmonellosis cases and estimated salmonellosis cases in the general population of the Netherlands, 1995-2005 (33, 34)
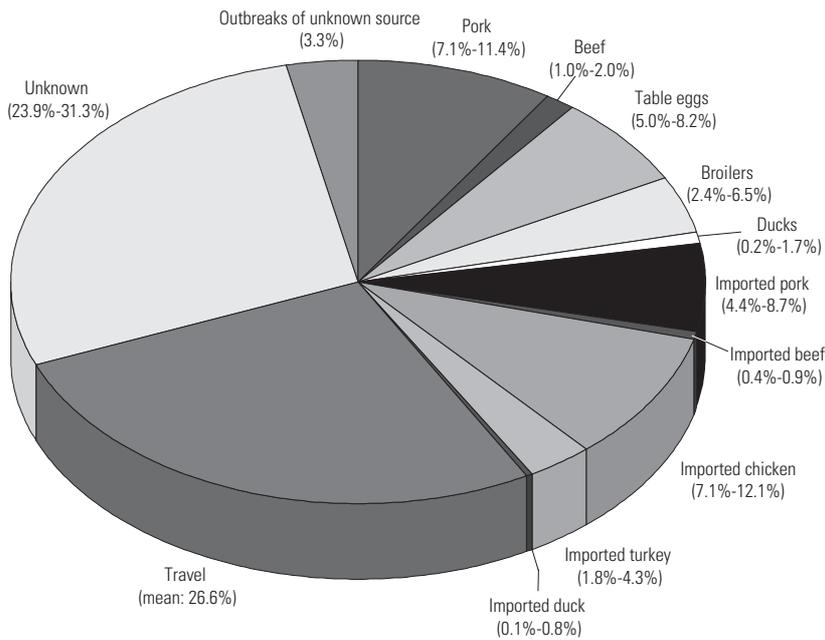

Fig. 2
Estimated sources of 1,538 cases of human salmonellosis in Denmark, 2004 (3)

abroad. The overall importance of this route of transmission may reflect the prevalence of *Salmonella* contamination of food (including food of animal origin) in a particular country. In low-prevalence countries, such as Finland, Norway and Sweden, > 80% of human cases of salmonellosis are attributed to visits abroad (3). This is in marked contrast to countries such as Denmark and the Netherlands (Figs 1 and 2), where roughly the opposite situation exists.

Risk mitigation options

In 1980, WHO had already formulated three lines of defence against *Salmonella*, which still comprise valid strategic approaches to risk mitigation (71):

a) the first approach focuses on controlling *Salmonella* in the food-producing animal (pre-harvest control)

b) the second approach involves improving hygiene during the slaughter and further processing of the meat (harvest control)

c) the third approach targets the final preparation of food by educating the food industry and consumers about good hygiene practices (post-harvest control).

Successful prevention of food-borne salmonellosis originating from animal production must involve all three lines of defence. The previously supported strategy that it is possible to control *Salmonella* only at consumer level, i.e. only at the third line of defence, has been abandoned (67).

Pre-harvest control of *Salmonella* at the farm level has long been considered an important part of pathogen reduction schemes (61), not least because traditional meat inspection cannot control *Salmonella*-contaminated carcasses. Indeed, the latter demonstrate how the industrialisation of animal production 'opened the door' of the food chain to pathogens like *Salmonella*.

Pre-harvest control

General aspects

There have been numerous international workshops and consultations on microbiological control and *Salmonella* reduction schemes in farming (35, 72, 73, 74, 75, 76). In addition, national inquiries directed principally at controlling *Salmonella* in poultry have been conducted in several countries in Europe, as well as Canada and the USA. A presentation of the Swedish *Salmonella* programme, supported by WHO, was of special interest (45).

In a review for the World Organisation for Animal Health (OIE) (66), on knowledge and experience in the prevention of salmonellosis on livestock farms, it was concluded that *Salmonella* control programmes should follow the same general rules that have been successfully applied to other infectious diseases (69). It is fundamental that monitoring programmes should be established to identify *Salmonella*-infected herds and animals and that efforts are made to find and control the sources of infection and prevent further spread. The ultimate objective is to produce *Salmonella*-free animals. It should also be emphasised that *Salmonella* is a pathogen and not a ubiquitous bacterium or a normal inhabitant of the intestinal flora of domestic animals, as has sometimes been claimed previously (66).

Specific aspects

Serovars to be controlled

Since any serovar, including those that infect animals or colonise their intestine, is a potential hazard to human health, measures to prevent food-borne salmonellosis must be directed at all serovars of *Salmonella*. However, a *Salmonella* reduction strategy which is limited to a few selected serovars should also have a preventive effect on most other serovars since the same advice for reducing any serovar applies. If such a strategy is implemented, a supporting surveillance programme will also be needed to detect the prevalence of zoonotic serovars and prevent their build-up in the production chain. If no interventions are made at this early stage, these serovars could later spread widely, perhaps reaching epidemic proportions.

Live animals as a source of infection

Salmonella-infected food-producing animals excrete *Salmonella* bacteria in large numbers, sometimes intermittently during their entire economic life. Excreted bacteria infect neighbouring animals on the farm and contamination of the environment takes place, with infections being transmitted to rodents and other wild fauna. When moved, the *Salmonella*-infected animals are effective at introducing the infection into their new holdings.

In the absence of 'guaranteed *Salmonella*-free replacement animals', other methods must be used to limit the risk of introducing *Salmonella* with incoming animals. In general, animals should be introduced only from herds of the same or a higher health status. Integrated production limits the need to introduce animals from other herds and thus the risk of introducing *Salmonella*-infected livestock. Networking between producers is an effective way to prevent respiratory and enteric infections in pig production, and should also prove suitable for limiting the risk of *Salmonella*.

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Diagnosis and monitoring methods

To combat the source of infection, the first requirement is to identify all *Salmonella*-infected animals on a livestock farm. Methods for this have been summarised in a WHO consultation report (76) on poultry production. Corresponding detailed guidelines have not yet been developed for other areas, e.g. for swine or beef/dairy production, but have long been applied successfully in Scandinavian countries.

Two principal methods are available:

– bacteriological

– immunological.

Bacteriological methods express the actual infection status of the animal, including recent transmission or contamination. They detect all serovars. The actual infectious agent (or, in the case of multiple infections, agents) is isolated, which makes further characterisation (e.g. serovar and antimicrobial resistance profile) possible. However, the analytical procedure is laborious.

Immunological methods identify previous exposure by detecting the presence of specific antibodies against *Salmonella*. This method can identify carriers or animals that are already clear of infection. It detects only those (most common) serogroups (O-antigens) included in the test and therefore new emerging serovars may not be detected. These methods are automated and less laborious.

A control programme also needs a supporting monitoring programme. Monitoring using bacteriological methods is needed to obtain a true picture of *Salmonella* status (38). Serological methods can be recommended, especially in medium- and high-prevalence countries, since they are cheap, fast and suitable for large-scale use, but their limitations should also be considered. They should be supplemented by the strategic use of bacteriological methods to ensure that emerging serovars, which might not otherwise be included in the tests, are also detected.

Hygiene and husbandry

Optimal hygiene and management routines are of major importance in aiding animals to withstand exposure to *Salmonella*, and to minimise the possible subsequent spread of the agent on the farm. Improvements in hygiene and management procedures must be continually implemented as a natural part of *Salmonella* control. Guidelines and recommendations have been presented by WHO (72), Blood and Radostits (7) and Schwartz (53).

Raising livestock in separate groups, without mixing animals from different sources and ages, has proved to be an effective health measure. The 'all-in, all-out' system, with careful cleaning and disinfection between batches, has

long been essential in broiler production (6), and is now also routine in *Salmonella* control programmes for beef and swine production. (This involves entirely emptying the stable/pen of animals before any new ones are introduced, so that infection cannot be passed on to incoming livestock.)

Violating these procedures has been empirically shown to result in deteriorating health status. In the advanced *Salmonella* control policies applied in poultry production, good hygiene routines have proved to be of basic importance (66). In a study involving several EU Member States, it was found that the risk of swine at slaughter testing seropositive for *Salmonella* infection was twice as high in herds with a continuous production system as in herds with a batch production system (37). The importance of providing good herd and pen hygiene in pig production, especially by limiting the faecal-oral transmission route, is further emphasised in a recent report by the European Food Safety Authority (EFSA) (16).

The control and eradication of immunodeficiency-causing diseases have been found to have significant health-supporting effects, in addition to the direct gains due to the absence of clinical disease. These diseases include the following:

– bovine virus diarrhoea

– enzootic bovine leukosis

– caprine arthritis/encephalitis in goats

– maedi-visna in sheep

– infectious bursal disease in poultry

– Aujeszky's disease (pseudorabies) in pigs.

Other enzootic diseases can thus predispose or increase the susceptibility of animals to *Salmonella* exposure.

Biosecurity systems should also prevent the introduction of *Salmonella* into a herd through, for example, wild animals, visitors or machinery (63). The importance of hygienic handling of manure is obvious, particularly considering that *Salmonella* is transmitted by faecal shedding and that the average number of animals per farm is increasing. Jones (31) reviewed the question of *Salmonella* in animal waste and presented recommendations for the storage and spread of manure, especially slurry.

According to several studies, improving hygiene and husbandry management programmes, as described above, is generally very cost effective (64).

Feed

In all countries, there is a constant risk that animals will be exposed to *Salmonella* through their feed (14, 21).

Considerable efforts should therefore be made to limit this exposure to an absolute minimum. Feed controls should follow the procedure described by Häggblom (24, 25). As *Salmonella* can seldom be detected in the final feed, unless the feed is heavily contaminated, it cannot be emphasised enough that control measures must be implemented before that stage. Programmes to prevent *Salmonella* in feedstuffs must be based on detecting the bacterium as early as possible in the production chain. A protocol involving hazard analysis at critical control points in the feed mill, including procedures for efficient cleaning and disinfection, should ensure that the processing line is not contaminated with *Salmonella* (59).

As shown by Edel *et al.* (13), pelleting can greatly reduce *Salmonella* contamination of the finished feed.

Certain feeds, such as fermented liquid feed used as a wet feeding system, and acidified feed or drinking water, have been found to reduce *Salmonella* in pig production (63).

Competitive exclusion

The use of competitive exclusion, in which the normal intestinal flora protects the host against invading pathogens, is a valuable part of *Salmonella* control in poultry farming. Competitive exclusion cultures have been used and tested in various countries, as reviewed by Schneitz and Mead (52). Positive results from the use of competitive exclusion have also been reported in pigs (22).

Vaccines

Many efforts have been made to find effective vaccines against *Salmonella* infections, especially in cattle and poultry but also in swine. A live attenuated vaccine against *S.* Gallinarum in poultry is available and there is currently demand for a vaccine to control *Salmonella* infections associated with human food poisoning, in particular, *S.* Enteritidis (20). However, due to the complicated pathogenesis of *Salmonella* infection, no significant breakthrough has been achieved (9). Vaccines to control *Salmonella* infections, especially inactivated vaccines, are in use all over the world. In recent years, increasing numbers of live vaccines have been developed but most of them are not yet authorised. Vaccination can play an important role in intervening against *Salmonella* in high-prevalence herds (23, 39, 46, 58). However, immunisation should not be conducted in isolation but always in combination with other measures, such as veterinary hygiene and improved management.

Antimicrobials

The use of antimicrobials to prevent suffering and economic losses in individual animals and herds can be justified, but should always be combined with other *Salmonella* reduction measures. Antibiotics have sometimes been used to prevent animals shedding *Salmonella* (36), but the use of antibiotics in pigs with enterocolitis has not been found to reduce the prevalence, magnitude or duration of *Salmonella* shedding by sick or recovered animals (70). Earlier, similar observations were made for experimental and natural *S.* Dublin infections in cattle (65). Both these findings agree with results from the use of antibiotics in human salmonellosis, i.e. that they have long been recognised to prolong the carrier state (4).

The use of antimicrobials for therapy or growth promotion may also disrupt the gut flora, which often increases the susceptibility of pigs to *Salmonella* infection. The use of antibiotics may thus act as a trigger to spread *Salmonella* infection throughout a herd, which would not have occurred if the animals remained untreated. This phenomenon has been thoroughly documented in poultry (57) and is also likely to occur in other animal species. The EFSA recently gave an opinion on the use of antibiotics to control *Salmonella* in poultry (15), which concurred with that of WHO (74), i.e. that *Salmonella* control should not be based on antibiotics. The emergence of antibiotic resistance is another serious reason why antibiotics should be used with great care, as demonstrated by the emergence and fast spread of the multi-resistant *S.* Typhimurium definitive phage type (DT) 104 (60).

In developed countries, it is also becoming increasingly accepted that a majority of the resistant strains of zoonotic *Salmonella* spp. have acquired that resistance in an animal host before being transmitted to humans through the food chain (42, 60). The prevalence of resistant isolates in countries where intensive animal production is practised is between 10% and 30%. When herds are held under strong antibiotic selective pressures, due to the intensive use of antibiotics, the prevalence of resistant strains rises to between 60% and 90% (26). As these bacterial strains are of considerable potential clinical importance to human health, this is a matter of real concern.

Strategies for implementation

The implementation of the mitigation options summarised above should all have a *Salmonella*-preventing effect. However, effective interventions also need specific targets and strategies for their application. In addition, if *Salmonella* does occur, despite these interventions, a progressive disease control plan should already have been prepared. Possible strategies for such approaches to control *Salmonella* have previously been formulated (66, 68). An intervention strategy should be based on the situation in the targeted herd, region or country.

In summary, the control of *Salmonella* at pre-harvest level must focus on preventive action because there is no 'silver bullet' through which the level of *Salmonella* contamination can be simply reduced. No single vaccine

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can prevent the infection, and the use of antimicrobials not only results in prolonged carriership but is also associated with the risk of developing antimicrobial-resistant strains. Both consequences pose public health hazards. Preventive action should follow the general rules that have already been successfully applied to control other infectious diseases.

In poultry production, rapid and positive results were demonstrated after the introduction of nationwide *Salmonella* reduction schemes. In Denmark, the prevalence of infection in broiler flocks declined from 12.9% in 1997 to 1.5% in 2002, resulting in an estimated 78% reduction of human cases related to domestically produced poultry products (44). Corresponding results have also been demonstrated in swine production, e.g. from Denmark (10). However, due to the more complex nature of swine, beef and dairy production, achieving positive results on a national basis would probably require a more long-term control programme, covering all steps of the production chain (32). A step-by-step approach to targeted interventions is advisable. The results should be viewed from a long-term perspective and the programme should be regularly re-evaluated to ensure compliance, efficacy and modification, if necessary.

Valuable experience can be gained from the EU, whose focus on preventing the spread of *Salmonella* in poultry is now directed to other animal species. Detailed rules are being established for harmonised *Salmonella* monitoring throughout the Community, to be followed by targets for reducing the prevalence of *Salmonella* serotypes with public health significance in pig herds. These will be based on appropriate legislation (18, 19). Within 18 months of these targets being set, Member States shall prepare and submit national control programmes to be approved by the Commission. The deadline for setting targets in pig production is December 2007 for breeding pigs and December 2008 for slaughter pigs.

Follow-up at harvest and post-harvest levels

If such pre-harvest *Salmonella* reduction interventions are supported by similar measures at harvest and post-harvest levels (which are, however, outside the scope of this paper), human exposure to *Salmonella* bacteria from animal food products should be considerably reduced. In Denmark, the herd prevalence of *Salmonella* in swine is estimated to have decreased from 22% to 11% in the four years following the implementation (1993/1994) of a *Salmonella* control programme (10). Through further interventions during slaughter, primarily hygienic killing procedures which avoid faecal contamination of carcasses, the prevalence of *Salmonella* in swine carcasses has been brought down to approximately 1% (17).

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Infection à *Salmonella* : une grave menace pour le commerce mondial des produits alimentaires d'origine animale

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Résumé

La salmonellose constitue la maladie bactérienne d'origine alimentaire la plus fréquente du monde. *Salmonella* est un agent pathogène important des animaux destinés à la consommation et ces animaux sont la source principale de salmonellose. Selon les estimations, la prévalence à l'échelle des troupeaux varie entre 0 et 90 %, selon l'espèce animale et la région. L'agent pathogène se propage lors du commerce d'animaux et de produits alimentaires d'origine animale non cuits. L'apparition de souches résistantes aux antimicrobiens, souvent à la suite de l'utilisation d'antimicrobiens chez les animaux, représente une menace grave pour la santé publique. Il est de plus en plus admis que la

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prévalence de *Salmonella* dans la production animale doit être réduite et, dans l'Union européenne, des plans visant cet objectif sont actuellement mis en œuvre. Dans cet article, les auteurs proposent différentes stratégies d'atténuation du risque. Une prophylaxie réussie doit être axée sur un ensemble d'actions préventives car il n'existe pas de solution miracle pour réduire la contamination par *Salmonella*. Les auteurs concluent que pour lutter contre *Salmonella*, il faut suivre les règles générales qui ont été appliquées avec succès à d'autres maladies infectieuses.

Mots-clés

Atténuation du risque – Épidémiologie – Îlot de pathogénicité liés à Salmonella – Maladie – Produit d'origine animale – Prophylaxie – Prophylaxie avant abattage – Résistance aux antimicrobiens – Salmonella – Salmonellose – Suivi – Virulence.
■

La salmonelosis: un importante problema para la comercialización a escala mundial de productos alimentarios de origen animal

L. Plym Forshell & M. Wierup

Resumen

La salmonelosis es la más frecuente de las enfermedades bacterianas que se transmiten por vía alimentaria en el mundo. *Salmonella* es un patógeno importante para los animales de los que se alimenta el hombre, animales que son a su vez la fuente primaria de salmonelosis. Se estima que la prevalencia del patógeno en los rebaños oscila entre un 0% y un 90%, según la especie animal y la región de que se trate. La actividad comercial es el cauce por el que las salmonelas se transmiten entre animales y contaminan productos alimentarios no cocinados. La aparición de cepas resistentes a los antimicrobianos, que suele ser consecuencia del uso de estos fármacos en animales, constituye un riesgo de salud pública que suscita gran preocupación. Cada vez está más claro que hay que reducir la prevalencia de *Salmonella* en la producción animal, y actualmente se están aplicando planes para lograr ese objetivo en la Unión Europea. Los autores proponen varias estrategias para mitigar riesgos. Dado que no existe una única solución "mágica" que pueda reducir los niveles de contaminación, la lucha contra la enfermedad, para resultar eficaz, debe integrar un conjunto de medidas preventivas. Los autores llegan a la conclusión de que la clave para luchar contra *Salmonella* estriba en seguir las reglas generales que se han aplicado con éxito en el caso de otras enfermedades infecciosas.

Palabras clave

Control – Control previo al sacrificio – Enfermedad – Epidemiología – Isla de patogenicidad de Salmonella – Mitigación de riesgos – Productos de origen animal – Resistencia a los antimicrobianos – Salmonella – Salmonelosis – Vigilancia – Virulencia.
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