Bacterial food-borne zoonoses

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In this paper, the terms describing serovars of Salmo nella have been abbreviated, for example, Salmonella Enteritidis refers to the organism Salmonella enterica subsp. enterica serovar Enteritidis.

Summary

In many countries of the world, bacterial food-borne zoonotic infections are the most common cause of human intestinal disease. Salmonella and Campylobacter account for over 90% of all reported cases of bacteria-related food poisoning world-wide. Poultry and poultry products have been incriminated in the majority of traceable food-borne illnesses caused by these bacteria, although all domestic livestock are reservoirs of infection. In contrast to the enzootic nature of most Salmonella and Campylobacter infections, Salmonella Enteritidis caused a pandemic in both poultry and humans during the latter half of the 20th Century. Salmonella Typhimurium and Campylobacter appear to be more ubiquitous in the environment, colonising a greater variety of hosts and environmental niches. Verocytotoxin-producing Escherichia coli O157 (VTEC O157) also emerged as a major food-borne zoonotic pathogen in the 1980s and 1990s. Although infection is relatively rare in humans, clinical disease is often severe, with a significant mortality rate among the young and elderly. The epidemiology of VTEC O157 is poorly understood, although ruminants, especially cattle and sheep, appear to be the major source of infection.

The dissemination of S. Enteritidis along the food chain is fairly well understood, and control programmes have been developed to target key areas of poultry meat and egg production. Recent evidence indicates that these control programmes have been associated with an overall reduction of S. Enteritidis along the food chain. Unfortunately, existing controls do not appear to reduce the levels of Campylobacter and VTEC O157 infections. Future control strategies need to consider variations in the epidemiologies of food-borne zoonotic infections, and apply a quantitative risk analysis approach to ensure that the most cost-effective programmes are developed.

Keywords


Introduction

Most people will experience at least one episode of food poisoning during their lifetime. In the United States of America (USA), it is estimated that one in ten people will experience bacteria-related food poisoning each year, of which the majority will be associated with Salmonella or Campylobacter (23). Similarly, a recent national surveillance study in England revealed that one in five people developed infectious intestinal disease each year, and that Campylobacter and Salmonella were the most common bacterial pathogens isolated (49). Indeed, Campylobacter was the most common of all pathogens isolated, ahead of group A rotaviruses. These trends are confirmed by the estimated national and international incidence of bacterial food-borne pathogens in Europe, the USA, Australia and Japan, in 1997 (Table I). Differences in collection and interpretation of data preclude comparisons between geographical locations, however, Salmonella and Campylobacter clearly predominate. This surveillance data highlights the continuing importance of food as a source of human gastrointestinal disease, of the
contamination with bacteria along the food-processing chain and, in particular, of the infection of domestic livestock with these bacterial pathogens.

Over the last twenty-five years, significant changes have occurred in the epidemiology of bacterial food-borne zoonoses along the food chain, and these changes have had a substantial impact on bacteria-related food poisoning in humans. At the beginning of the new millennium, it is pertinent to review these changes and reflect on the lessons which have been learnt for the future. This review considers the recent changes in the epidemiology of the major food-borne bacterial pathogens at the end of the 20th Century with reference to Salmonella, Campylobacter and Escherichia coli O157. The effectiveness and public health importance of current control methods employed along the food chain are discussed. The review is concluded by offering a personal perspective for the future control of these food-borne zoonotic organisms.

Changing perspectives: 20th and 21st Centuries

**Salmonella**

There is no doubt that the overall burden of Salmonella infection in domestic livestock worldwide has increased over the period from 1985 to 2000, due mainly to the evolution of the S. Enteritidis pandemic in the 1980s (33, 36). Similarly, the great majority of cases of food poisoning in humans caused by Salmonella are associated with contaminated animal products, and therefore a similar rise has occurred in human cases (24). The source of the pandemic of S. Enteritidis is considered to be a number of closely related events which caused the contamination of flocks at the top of the breeding pyramid with one or more phage types (PT) of S. Enteritidis (24). Thus, rapid spread of S. Enteritidis infection occurred very quickly to most parts of the world, possibly through the vertical transfer of the bacterium via chick embryos. This hypothesis is supported by the fact that Australia, which has very strict rules on the importation of animal products, including regulations on the importation of poultry and hatching eggs, has remained largely free of S. Enteritidis (44). The original discrimination of PT by geographical location could be considered as a result of international trade (i.e. S. Enteritidis PT4-infected birds predominated in western Europe, whereas S. Enteritidis PT1 and PT8 predominated in North America, eastern Europe and parts of Scandinavia). Not surprisingly, mixing of the S. Enteritidis PTs has occurred across the world over the last fifteen years, particularly PT4, although even now, the original PT remains predominant over others in different parts of the world (36). Figure 1 illustrates the increased incidence of S. Enteritidis in domestic livestock and humans in the United Kingdom (UK) since 1976 and reflects similar trends in many other countries (24). In the UK, peak infection in livestock, especially chickens and turkeys, was observed in the early 1990s. Between 1992 and 1998, a steady decline occurred, due in part to national and European controls instigated in the 1980s in the poultry breeding sector. In other parts of Europe, such as Denmark, the Netherlands and Ireland, this decline has been spectacular. In the USA, S. Enteritidis incidence in domestic livestock and humans has not been significantly reduced. One reason for this was the introduction of PT4 to North America in the 1990s. This PT now competes with PT8 as the most common S. Enteritidis isolated from chickens (2). Interestingly, the decline of S. Enteritidis in humans in the UK has been less pronounced, and may reflect the continued persistence of S. Enteritidis in laying hens, which maintains the levels of contaminated eggs and egg products seen during the pandemic. This has also been noticed in other countries (24).

<table>
<thead>
<tr>
<th>Zoonosis</th>
<th>Europe</th>
<th>USA</th>
<th>Australia</th>
<th>Japan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salmonellosis</td>
<td>73</td>
<td>14</td>
<td>38</td>
<td>ND</td>
</tr>
<tr>
<td>Campylobacteriosis</td>
<td>30</td>
<td>25</td>
<td>100</td>
<td>ND</td>
</tr>
<tr>
<td>VTEC infections</td>
<td>0.7</td>
<td>2.0</td>
<td>100</td>
<td>ND</td>
</tr>
<tr>
<td>Listeriosis</td>
<td>0.2</td>
<td>0.5</td>
<td>0.4</td>
<td>ND</td>
</tr>
<tr>
<td>Yersiniosis</td>
<td>2.0</td>
<td>1.0</td>
<td>1.5</td>
<td>ND</td>
</tr>
<tr>
<td>Brucellosis</td>
<td>1.0</td>
<td>ND</td>
<td>ND</td>
<td>ND</td>
</tr>
</tbody>
</table>

Sources:
- a) European Commission, 1999 (16)
- b) Anon., 1999 (6)
- c) O'Brien et al., 1999 (31)
- d) Anon., 1997 (3)
- e) Anon., 1998 (5)
- ND : no data
- VTEC : verocytotoxin-producing Escherichia coli

![Fig. 1 Isolations of Salmonella Enteritidis from animals in Great Britain and humans in England and Wales, 1976-1998](image-url)}
diarrhoea thought to be responsible for fifty-eight cases of human food poisoning in Germany, via the illegal distribution of meat. This is the first report of food poisoning linked to Salmonella (45). Salmonella Enteritidis was sporadically isolated from poultry and eggs in the 1930s, and contaminated eggs were found to be a result of infection of the avian oviduct, and in some cases, penetration of the shell (38). Interestingly, the potential of egg-based dishes, such as mayonnaise, as sources of food poisoning was already recognised at this time (38). Nevertheless, for eighty years or more, S. Enteritidis behaved like many hundreds of Salmonella serotypes that are isolated regularly from animals at low baseline levels and that have very little impact on the food chain. In hindsight, three factors probably combined to produce the rapid spread and persistence of S. Enteritidis seen since the 1980s, namely: the rapid consolidation of breeding flocks of a few companies at the top of the pyramid, the exposure of this elite breeding stock to S. Enteritidis, and the ability of specific strains of the organism to colonise the reproductive tract and infect eggs.

If S. Enteritidis is controlled at all levels of the poultry sector, especially egg production, incidence may continue to decline to levels seen prior to the mid-1980s, and the bacterium may occur only sporadically as a food-borne zoonotic pathogen associated with intermittent food and environmental contamination. However, strictly observed controls and rigorous monitoring systems will have to be instigated and maintained in the poultry sector to ensure freedom from contamination. Even in those countries that have suffered severe epidemics of S. Enteritidis, only at the peak of the epidemic cycle has the incidence of S. Enteritidis in all domestic livestock been greater than that of S. Typhimurium, despite the fact that human food poisoning caused by S. Enteritidis is far more prevalent. This observation emphasises the crucial importance and role of contaminated egg products as vehicles for S. Enteritidis food poisoning.

Salmonella Typhimurium is also commonly associated with human food-borne infections (33, 37). In many countries that implemented Salmonella control programmes in the poultry sector in the 1990s, S. Typhimurium has regained its position as the most common serotype isolated from all domestic livestock (7, 16). The epidemiology of this serotype is quite different from S. Enteritidis in several ways. Most of the enteric salmonellas are able to colonise many types of livestock and persist in a variety of environmental niches along the food chain. Nevertheless, specific serotypes do seem to thrive in particular animal hosts. For example, S. Enteritidis has predominated in poultry, especially chickens, whereas S. Derby and S. Montevideo are more commonly isolated from pigs and sheep, respectively (16). In contrast, S. Typhimurium is truly ubiquitous and a number of species of animal and poultry are able to act as maintenance hosts (Table II). One possible reason for this is that S. Typhimurium is a very heterologous serotype, comprising hundreds of determinative types (DT) able to regulate and express genes associated with virulence, stress response and host specificity in subtly different ways. This is in direct contrast to S. Enteritidis which predominantly comprises a small number of closely-related genetic clones. Some key features of S. Typhimurium epidemiology are illustrated in Figure 2 which plots the isolations from domestic livestock in the UK between 1976 and 1998, and highlights the associations between outbreaks in humans and isolations in livestock for certain DTs. For at least several decades, and probably longer, S. Typhimurium has been enzootic in domestic livestock in the UK (Fig. 2), and in many other countries, including the USA and most of mainland Europe (16). During this period, individual DTs have caused epidemics of varying severity in animals and humans. For example, in the mid-1980s in the UK, an increase in S. Typhimurium DT204 and related types was observed in animals. This rise was mirrored by an increase, in particular, of S. Typhimurium DT204c in humans, which accounted for the rise in all S. Typhimurium cases identified in the UK. This particular DT was unusual in that it almost exclusively infected calves and spread through the calf population via livestock markets (50). It also acquired plasmids conferring multiple antimicrobial resistance. In direct contrast, in the early 1990s, incidence of DT104 increased rapidly in domestic livestock, especially cattle, but also pigs and poultry, with the concurrent increase in isolations of S. Typhimurium in humans, due almost entirely to DT104. Evidence shows that this epidemic strain, with chromosomally integrated multiple drug resistance, has spread efficiently through the food chain in the USA, Canada and Europe (13). The DT104 outbreak was much larger than the previous DT204 outbreak (Fig. 2). However, both epidemics lasted approximately eight years and declined rapidly to lower isolation levels. Research to ascertain the reasons for these observed declines and differences in host specificity at the environmental and molecular levels would provide useful information that could help to predict the nature of future epidemics caused by different DTs of S. Typhimurium.

Campylobacter

Campylobacter was first identified as a pathogen in animals about ninety years ago (40), although it was not until 1972 that Butzler et al. first demonstrated the association between human enteric illness and Campylobacter jejuni (12), a result

<table>
<thead>
<tr>
<th>Livestock</th>
<th>Salmonella Enteritidis</th>
<th>Salmonella Typhimurium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adult cattle</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>Calves</td>
<td>2</td>
<td>38</td>
</tr>
<tr>
<td>Sheep</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Pigs</td>
<td>1</td>
<td>17</td>
</tr>
<tr>
<td>Poultry</td>
<td>93</td>
<td>13</td>
</tr>
</tbody>
</table>

Percentage of all incidents reported in the United Kingdom in 1997

Table II

Salmonella Enteritidis and Salmonella Typhimurium in domestic livestock in the United Kingdom, 1997
which was confirmed shortly afterwards by Skirrow (39). Between 1975 and 2000, reported cases of human illness caused by Campylobacter have inexorably risen year by year in the developed world. Compared to Salmonella, an estimation of the prevalence of infection in the human population is difficult due to the infancy and paucity of surveillance systems for Campylobacter. However, currently available estimates show that cases of human campylobacteriosis now exceed those of salmonellosis in several countries of Europe (Table III). The continued rise in incidence of human campylobacteriosis is well illustrated by the data from Denmark (Fig. 3), where incidence increased from 20 per 100,000 to 64 per 100,000 between 1980 and 1998, although much of the increase, nearly three-fold, has occurred since 1992. Similar rises have been observed in the UK in recent years (4). As is the case with any newly identified organism associated with illness, the ascertainment rate increases over many years. Due to the very recent publicity afforded to Campylobacter, this ascertainment rate is probably still increasing. However, the dramatic rise in cases of human campylobacteriosis recorded in many countries indicates that other significant factors are involved. Case control studies in a number of countries of Europe indicate that the handling or consumption of chicken meat may account for at least 50% of sporadic human campylobacteriosis (25). Limited data are available on prevalence in chicken flocks, restricted mainly to longitudinal studies involving small numbers of flocks. These data do indicate that infected chicken broiler flocks are common. For example, prevalences in chicken flocks of between 10% and 50% have been observed in Scandinavia, whereas in the UK and the Netherlands, figures approaching 90% have been reported (29). Once a flock is colonised, nearly all birds become infected very rapidly, thus significant proportions of raw poultry meat for human consumption become contaminated with Campylobacter. Consumption of chicken is undoubtedly a major source of campylobacteriosis. However, recent work has indicated that other major vehicles of infection are likely, and advances in the molecular

![Fig. 2]

Isolations of Salmonella Typhimurium from animals in Great Britain and association of DT104 and DT204 with outbreaks in humans in England and Wales, 1976-1998
Table III
Salmonellosis and campylobacteriosis in humans in the European Union in 1997
Incidence rate per 100,000 population

<table>
<thead>
<tr>
<th>Country</th>
<th>Salmonellosis</th>
<th>Campylobacteriosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>107</td>
<td>21</td>
</tr>
<tr>
<td>Denmark</td>
<td>95</td>
<td>50</td>
</tr>
<tr>
<td>Finland</td>
<td>58</td>
<td>47</td>
</tr>
<tr>
<td>France</td>
<td>33</td>
<td>ND</td>
</tr>
<tr>
<td>Germany*</td>
<td>128</td>
<td>70</td>
</tr>
<tr>
<td>Ireland</td>
<td>29</td>
<td>ND</td>
</tr>
<tr>
<td>Italy</td>
<td>26</td>
<td>ND</td>
</tr>
<tr>
<td>Sweden</td>
<td>48</td>
<td>60</td>
</tr>
<tr>
<td>The Netherlands</td>
<td>16</td>
<td>23</td>
</tr>
<tr>
<td>Scotland</td>
<td>85</td>
<td>108</td>
</tr>
<tr>
<td>Northern Ireland</td>
<td>26</td>
<td>47</td>
</tr>
<tr>
<td>England and Wales</td>
<td>61</td>
<td>96</td>
</tr>
</tbody>
</table>

* Data related to parts of Germany only
ND: no data

fingerprinting of campylobacters indicate that some degree of host specificity exists amongst campylobacters. Thus, campylobacters can be divided into poultry, human and poultry/human groups (29). Epidemiological data from Scandinavia have demonstrated that the seasonal peak of infection in humans, in early and mid-summer, precedes a similar peak observed in chickens. In Sweden, where flock prevalences have declined, human campylobacteriosis has increased. These epidemiological observations indicate sources other than chicken products. A recent case control study in Denmark on sporadic campylobacteriosis in humans associated foreign travel with an increased risk of infection. Risk factors other than chicken included barbecue-prepared beef, veal or pork, drinking water with a bad odour, especially from a well, and contact with cats with diarrhoea (20). *Campylobacter* appears even more ubiquitous than *Salmonella* and contaminates many different types of environmental and food sources of human infection. A better understanding of the various *Campylobacter* cycles in the food chain is fundamental to developing better control and intervention strategies.

**Escherichia coli**

A new, emerging, clonally distinct form of *Escherichia coli* was first identified as a significant food-borne zoonotic pathogen in 1982, when it was associated with an outbreak in the USA of severe bloody diarrhoea that was traced to the consumption of undercooked hamburgers (35). The *E. coli* isolated from the patients was serotyped as O157:H7, which hitherto was considered an extremely rare serotype, reported only once previously, in 1975, from a patient with bloody diarrhoea in the USA. In this case, the source of the infection was unknown. It was not until 1983 that *E. coli* O157:H7 strains associated with severe bloody diarrhoea in humans were shown to produce one or more closely related toxins, now termed verotoxin (VT) or shiga-like toxin (SLT) (26). Verocytotoxin-producing *E. coli* O157:H7 (VTEC O157) has since emerged as a major food-borne pathogen which has most severe effects on young children and the elderly. A retrospective study on strains of *E. coli* isolated from healthy cattle in Argentina in 1977 typed a proportion of these strains as VTEC O157. These are probably the first documented isolates of this organism from cattle and other domestic livestock (14). Recent evidence supports a model in which O157:H7 evolved sequentially from an O55:H7 ancestor, first acquiring the VT gene and then diverging into two closely related branches. One of these branches resulted in the O157:H7 clone that spread world-wide, and the other lost motility, leading to O157:H- which is increasing in importance in Germany and other parts of Europe (17).

Overall, approximately 5% of infected individuals develop haemolytic uraemic syndrome (HUS), which is characterised by haemolytic anaemia, thrombocytopenia, renal failure and mortality of 3% to 5% (19). However, in outbreaks involving elderly patients, morbidity can be much higher. For example, during recent outbreaks in England and Wales, 38% of cases were hospitalised, 21% of cases developed HUS, and the case fatality rate was 3% (47). Strains of VTEC capable of producing severe bloody diarrhoea in humans are referred to as enterohaemorrhagic *E. coli* (EHEC). Since the early 1980s, reports of cases of VTEC O157 in humans in many developed countries, particularly the USA, Canada, Japan and the UK, have increased steadily. This is illustrated by recent figures from Japan and the UK, which show large increases in reported laboratory isolations in the late 1990s (Figs 4 and 5) (8).

A large outbreak of VTEC O157 infection occurred in the western USA in 1992 and 1993, associated with the consumption of hamburgers at restaurants and one fast-food chain. On this occasion, VTEC O157 isolated from some of the hamburger batches were indistinguishable from those
isolation from patients, thereby confirming the importance of bovine food products, especially beef, as vehicles of infection (35). Many other foods have now also been implicated, including beef and dairy products and faecally-contaminated fruit and vegetables.

Many estimates of the prevalence of faecal excretion of VTEC O157 in cattle tend to be unstructured and biased towards diseased animals. However, there have been adequate studies world-wide to suggest that low national animal prevalences predominate. Thus, prevalences of 0.86% and 0.25% have been reported from bovine faeces in England and Wales, and Scotland, respectively (34, 42). Results from a national abattoir survey in the UK in 1994 produced an estimate that 0.47% of beef carcasses leaving abattoirs were contaminated with VTEC O157 (34). A small-scale survey conducted in Denmark in 1998, found 0.4% of bovine faecal samples to contain VTEC O157 (20). Low prevalences of VTEC O157 excretion by animals have also been reported from other countries such as the USA (21), New Zealand (11), Sweden (1), Spain (10) and Germany (28).

Seasonality in excretion has been demonstrated recently in a longitudinal study of cattle in the UK. Infection as measured by faecal excretion was rare in the winter and peaked in the summer months, although the excretion was intermittent (27). Intermittent excretion was also observed in follow-up studies of two herds in the UK which were traced to human infection (51), and has been a similar feature of the herds investigated in the USA (48). Intermittent excretion has also been reported in a number of experimental VTEC O157 infections in calves and adult cattle (51). Another uniform finding of studies in the USA, Spain, Sweden, Germany, the UK and Canada is age-related prevalence, in that animals of less than twenty-four months of age are likely to have a greater prevalence of faecal excretion.

In contrast, the prevalence of infected herds is likely to be much higher than that observed for individual animals. Most studies have been performed in the USA with reported herd prevalences approaching 100% (21, 48, 52). A study published in the UK also indicates a high herd prevalence (42). Faecal excretion of VTEC O157 in sheep, and contamination of sheep products, notably burgers made with lamb, has been reported. Isolates from sheep appear identical to those from cattle, although as yet no direct food link to human infection has been made. Pigs also excrete VTEC O157, but express a different variant of VT which is associated with oedema disease and currently does not appear to be a major source of human infection. There is no evidence that poultry is a source of VTEC O157, although very little research has been performed in this area (14). Researchers in the USA have infected chicks experimentally with VTEC O157 and shown that the birds are easily colonised and excrete the organism for several months after infection. This observation is of some concern, although all the studies used the same laboratory strain with unusually high resistance to naladixic acid (14). Further studies using more typical field isolates will help to clarify the position, and continued monitoring of chicken flocks would be prudent.

Unlike Salmonella and Campylobacter, the infectious dose for human VTEC O157 is likely to be very low. Circumstantial evidence from past outbreaks demonstrates an ability to spread via contaminated water, milk (41) and apple cider (9). An outbreak reported in the USA implicated dry fermented salami (43). A quantitative analysis of the outbreak of 1992-1993 in the western USA provides further evidence relating to the potential infectious dose. For example, the median most probable number of VTEC O157 was 1.5 organisms per gram or 67.5 organisms per hamburger. This suggests an infectious dose for VTEC O157 in this outbreak of fewer than 700 organisms (46). These findings
have significant consequences for the control of VTEC O157 in animals and animal products, as described later in this paper.

In a recent review, VTEC O157:H7 isolates were reported to account for only approximately 60% of EHEC isolates from human outbreaks. A number of outbreaks and cases of sporadic disease caused by non-O157:H7 EHECs have been reported over the last twenty years, with the most common serotypes being O111 and O26 (18). However, only one of these outbreaks (O111:H− in fermented mettwurst sausage) has ever been attributed to a contaminated food source which may or may not have arisen from animals (32). Whilst current evidence does not suggest significant animal reservoirs of non-0157:H7 organisms with the potential to infect humans, current detection methods used for the isolation of VTEC O157 in animals would not routinely isolate and identify other EHECs. Clearly, this situation needs to be reviewed regularly and addressed if circumstantial evidence indicates that animals and animal products may be a significant reservoir of human non-0157:H7 infections.

**Effectiveness of current control methods along the food chain**

Due to the potential for cross-contamination during slaughter and processing of livestock, a prerequisite for a significant and sustainable improvement in human disease is a substantial reduction of bacterial pathogens in domestic livestock, approaching total elimination. However, in the case of *Salmonella* in pig meat, optimising the slaughter process can reduce the potential risks associated with infection in pigs submitted for slaughter. Until recently, salmonellosis caused by *S. Enteritidis* and *S. Typhimurium*, associated with consumption of poultry products, comprised the vast majority of reported human food-borne zoonotic cases, thus control measures have been specifically designed and formulated to reduce the prevalence of these serovars in the poultry sector. However, the importance of *Salmonella* in pigs and *Campylobacter* in poultry has been recognised recently, and in a few countries control measures seek to address these situations. The future control of VTEC O157 in domestic livestock will provide a unique challenge due, in part, to the high herd prevalence and low individual animal prevalence, intermittence of faecal excretion, apparent lack of host response to colonisation of the gut and the likely very low infectious dose for humans.

Figure 6 illustrates the principal contamination routes for the potential introduction of *Salmonella* and *Campylobacter* to poultry flocks. Similar routes of infection also apply to other domestic livestock. Any successful control of food-borne zoonotic pathogens requires an extensive and integrated risk-based prevention approach, with key point surveillance to monitor success and immediate corrective action where appropriate. To date, risk analysis relating to food-borne zoonoses has used a semi-quantitative approach based on available published evidence and expert opinion. For example, the initial control of *S. Enteritidis* in poultry focused on removing vertical transmission via breeding stock and replacement chicks, whereas the control points for *S. Typhimurium* and other serovars concentrated more on the reduction of feed and environmental contamination and improved biosecurity. Despite tens of thousands of published research papers on the detection and control of food-borne zoonoses in animals, limited data have been published on the success or otherwise of national and international control programmes. This is probably due to the integrated, multifaceted and expensive nature of any successful control programme. Nevertheless, a small number of national and international control programmes have been in operation for a number of years and a preliminary assessment of their effectiveness can be made.

**United States of America**

A producer-driven pilot quality assurance programme for *S. Enteritidis* in eggs was initiated in Pennsylvania in 1992 and was named the Pennsylvania Egg Quality Assurance Program (PEQAP). The PEQAP targeted interventions to reduce *S. Enteritidis* in both eggs and flocks. Infected flocks identified by regular environmental sampling were required to submit eggs for bacteriological culture. If any of the eggs tested positive, the producer diverted the eggs from that flock to pasteurisation or hard boiling. The PEQAP continued until 1995 as a pilot study, and the effectiveness of the controls have been estimated, but not quantitatively measured. However, *S. Enteritidis* in infected flocks was reduced from 40% to 15%, according to environmental sampling during the course of the PEQAP. Associated with this decline was a reduction in *S. Enteritidis* isolation rates in humans from approximately 9 per 100,000 population to 7 per 100,000 population in the mid-Atlantic region which constitutes the market for eggs produced in Pennsylvania. It was concluded that combined efforts of the egg producers, retail outlets and food handlers had a positive impact on public health in the mid-Atlantic region (22). The relative effectiveness of different measures along the food chain could not be assessed, but since publicity surrounding *S. Enteritidis* in eggs predated the implementation of the PEQAP by some ten years, it is reasonable to conclude that the reduction of *S. Enteritidis*-contaminated eggs during the PEQAP contributed significantly to the effectiveness of the overall programme along the food chain. However, at the national level, neither the incidence of human illness due to *S. Enteritidis*, nor the prevalence of *S. Enteritidis* in flocks and unpasteurised liquid eggs has decreased significantly, despite national control programmes targeted at egg producers, food handlers and food-handling practices. This highlights that the effectiveness of control strategies rely on sensitive flock monitoring techniques and a fully integrated, co-operative and
Hatchery
(Salmonella only)

Replacement chicks
(Salmonella only)

Feed and water

Poultry flock

Environmental factors

Chicken meat and eggs

Contact with other livestock

Cleaning and disinfection

Insect, rodent and bird control

Ventilation

Visitors

Fig. 6
Principal contamination routes of poultry flocks with Salmonella and Campylobacter

co-ordinated approach. Control programmes should ideally be driven by the producers to ensure the high participation rates which were apparent in the PEQAP.

Europe
In 1992, the European Union (EU) passed a Directive implementing harmonised rules for the control of S. Enteritidis and S. Typhimurium in breeding flocks of domestic fowl throughout the Member States (15). This has provided a framework for the national statutes of many countries, such as Sweden, Denmark, the Netherlands, France and the UK, where areas such as commercial broiler and layer flocks have been introduced.

In the UK, an overall decline in the number of incidents of S. Enteritidis and S. Typhimurium reported annually in breeder flocks has occurred since 1991. This decline probably reflects the current effectiveness of the legislative controls and the extensive efforts of the poultry breeding companies. The evidence also suggests that these controls and other management measures, such as vaccination of parent flocks, have had a positive impact on the number of infected broilers. However, in a number of commercial laying flocks, maintenance and persistence of S. Enteritidis remains a problem (24). This is reflected in the statistics for Salmonella infection in humans: although a decline in cases was reported in 1997 and 1998, this is not as marked as the decline of S. Enteritidis in animals (Fig. 1), and contaminated eggs and egg products remain the major traceable source of S. Enteritidis food-borne infections.

Denmark and Sweden have the most extensive Salmonella control programmes anywhere in the world. These cover Salmonella in poultry and pigs and also include surveillance for Campylobacter in broiler chickens. The relative effectiveness of the control programmes in Denmark can be assessed by examining the published estimated food sources of human salmonellosis in Denmark from 1988 to 1998 (Fig. 7). Although recognised as a rather crude assessment, the figures clearly show the dynamics in the changing sources of human salmonellosis over a ten-year cycle. Denmark experienced three waves of human salmonellosis, in each of which the majority of cases were attributed to a different food source. In the late 1980s, broilers were the major food source, whereas in the mid-1990s, pork products increased in significance, and from the mid-1990s to the end of the century, eggs and egg products predominated.
At each of the peaks of human salmonellosis in Denmark, new control programmes in animals were implemented which resulted in a reduction of human cases attributable to that particular food source. This is the clearest evidence to date that intensive and co-ordinated Salmonella control programmes in animals can effect a reduction in human salmonellosis from that food source. It also provides sound evidence that controlling food-borne pathogens in animals is a very important control point in the entire food chain.

Certain aspects of the experience in Denmark are worth noting. Firstly, the broiler control programme was originally a voluntary programme targeting the breeder sector, and secondly, in 1992, official ante-mortem examination of all flocks submitted for slaughter was initiated so that flocks testing negative for Salmonella could be slaughtered separately from those found to be infected. The combination of the national programme and the EU zoonoses Directive 92/117/EEC (16) resulted in the steady decline of contaminated commercial broiler flocks and chicken meat as a source of human infection. Similar controls were instigated for Salmonella in eggs and pork, although the decline in infection following the beginning of these programmes appears to have been much slower in both animals and humans. The reasons for this are not entirely clear, however, one of the key components in any successful programme is effective surveillance to identify infected groups of animals. Detection methods need to reflect the reduction in prevalence of infection as control programmes become effective. This requires increased sensitivity of detection methods while retaining a high level of specificity to avoid false positives and unnecessary and costly follow-up investigations. In Denmark, the methods currently used for the microbiological detection of Salmonella in broilers exhibit high sensitivity, partly due to the high and consistent levels of faecal excretion. In contrast, the bacteriological detection of Salmonella in pigs and laying hens does not match the performance of the tests used in broilers, possibly due in part to different types of sample. In Denmark, this problem has been recognised and additional serological surveillance has been implemented using blood, or in the case of pigs, tissue fluid from muscle samples. These measures have resulted in increased test sensitivity and hence the identification of a larger proportion of the infected flocks or herds at an earlier stage. The effect of these changes to the control programme on the rate of decline of animal and human infection should be known in the next few years. It should be noted, however, that the general management and husbandry control measures applied to Salmonella in broilers appear to have less effect on the number of Campylobacter-infected flocks.

Whilst these successful control programmes provide very useful models for others, future control strategies will also be informed by formal quantitative risk analysis which will identify the critical control points associated with the highest risk of acquiring and spreading the infection (30). Quantitative risk analysis studies are currently being initiated in the UK for the control of Campylobacter in poultry along the food chain, and S. Enteritidis in commercial table eggs (M. Wooldridge, personal communication). These and future...
studies will hopefully provide a more scientific and cost-effective basis for the control of these organisms. In particular, control programmes such as those described above are very expensive and are beyond the scope of many countries. It is to be hoped that formal risk analysis exercises will be able to quantify the risks of infection and relate these risks to their cost-effectiveness. This will enable different countries to rationally design control programmes to suit the financial resources available in each country.

Conclusion

At the end of the 20th Century, bacterial food-borne zoonoses have become the major cause of infectious intestinal disease in humans in many developed countries, replacing infections classically associated with poorly developed sanitary and housing conditions, such as cholera, typhoid and dysentery. The integration and globalisation of the food-processing chain has facilitated the rapid spread of infections such as Salmonella and Campylobacter. The most notable example of this is the S. Enteritidis pandemic of the 1980s and 1990s. However, other factors, including the emergence of new food-borne pathogens, have also had a considerable impact. In particular, the emergence of VTEC O157 in the early 1980s, through the acquisition of relevant genetic material by an otherwise commensal bacterium, is a powerful example of the potential of new and emerging pathogens to spread rapidly through animal and human populations.

Paradoxically, the integration and globalisation of food production also offers improved opportunities for the control of many of these pathogens. Evidence now exists to prove that concerted and co-ordinated control programmes such as correctly targeted, hazard analysis and critical control point (HACCP) have had a positive impact on the control of, for example, Salmonella in chickens. Early indications also demonstrate a positive impact on human infections.

In future, quantitative risk analysis will assume greater importance in the identification of those points along the food chain that contribute most cost-effectively to the control and spread of the organisms. As a result, improved, cost-effective control programmes should be developed, thus offering new opportunities to countries in which control methods have hitherto been considered too expensive. The lessons of the last thirty years have also clearly indicated the importance of surveillance in any control programme, not only to identify emerging problems, but also to demonstrate the effectiveness of the programmes themselves.

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Zoonoses bactériennes d’origine alimentaire

C.J. Thorns

Résumé

Dans nombre de pays, les zoonoses bactériennes d’origine alimentaire sont la cause la plus fréquente de maladies intestinales chez l’homme. Salmonella et Campylobacter sont à l’origine de plus de 90 % des cas signalés de toxï-infections alimentaires dues à des bactéries dans le monde. Les volailles et les produits de l’aviiculture ont été incriminés dans la plupart des maladies reconnues comme d’origine alimentaire et causées par ces bactéries, mais tous les animaux domestiques constituent des réservoirs. Alors que la plupart des infections dues à Salmonella et Campylobacter sont de nature enzootique, Salmonella Enteritidis a été l’agent responsable d’une pandémie chez les volailles comme chez l’homme au cours de la deuxième moitié du vingtième siècle. Salmonella Typhimurium et Campylobacter semblent plus ubiquistes dans l’environnement, colonisant une grande variété d’hôtes et de biotopes. Escherichia coli O157 verocytotoxynogène (VTEC O157) est également apparu dans les années 1980 et 1990 comme un agent pathogène majeur responsable de zoonoses d’origine alimentaire. Si l’infection
est relativement rare chez l’homme, les manifestations cliniques sont souvent graves, avec un taux de mortalité élevé chez les jeunes et les personnes âgées. On possède peu de données épidémiologiques sur VTEC 0157, mais les ruminants, notamment les bovins et les ovins, semblent en être les hôtes principaux.

La dissémination de S. Enteritidis le long de la chaîne alimentaire est assez bien connue et des programmes de prophylaxie ont été élaborés, visant les secteurs clés de la production d’œufs et de viande de volaille. Des données récentes montrent que ces programmes de prophylaxie ont conduit à une réduction globale de S. Enteritidis le long de la chaîne alimentaire. Malheureusement, les moyens de lutte actuels ne semblent pas diminuer les infections dues à Campylobacter et à VTEC 0157. Les stratégies de prophylaxie à venir doivent tenir compte des variations épidémiologiques des zoonoses d’origine alimentaire et se fonder sur une analyse quantitative des risques pour que les programmes mis en place présentent le meilleur rapport coût-efficacité.

Mots-clés

Zoonosis bacterianas transmitidas por vía alimentaria
C.J. Thorns

Resumen
En muchos países del mundo, las bacteriosis zoonóticas transmitidas por vía alimentaria son la causa más común de enfermedades entericas humanas. Los géneros Salmonella y Campylobacter dan cuenta de más del 90% del total de toxo-infecciones bacterianas por vía alimentaria que se declaran en el mundo entero. Pese a que todos los animales domésticos de granja constituyen reservorios de infección, las aves de corral y los productos avícolas son responsables de la mayoría de las toxo-infecciones alimentarias por dichos patógenos cuyo origen es factible determinar. En contraste con el carácter enzootico de buena parte de las infecciones por Salmonella y Campylobacter, durante la segunda mitad del siglo XX se produjo una pandemia por Salmonella Enteritidis que afectó tanto a las aves de corral como al ser humano. Salmonella Typhimurium y Campylobacter parecen gozar de una presencia más ubicua en el medio, colonizando una mayor variedad de huéspedes y nichos ecológicos. Escherichia coli 0157 verocitotoxigénica (VTEC 0157) se reveló asimismo durante los años ochenta y noventa como un importante patógeno zoonótico de transmisión alimentaria. Aunque esta infección es relativamente rara en el hombre, su expresión clínica suele revestir bastante gravedad, con una importante tasa de mortalidad entre niños y personas de edad. Muy poco se sabe de la epidemiología de este microorganismo, aunque parece que los rumiantes, en especial los bovinos y ovinos, constituyen la fuente más importante de VTEC 0157.

En cambio, se conocen bastante bien los mecanismos de propagación de S. Enteritidis en la cadena alimentaria, lo que ha permitido elaborar programas de control para su aplicación en áreas clave de la producción de carne de ave y huevos. A juzgar por los datos más recientes, la aplicación de esos programas se ha traducido en una reducción general de la presencia de S. Enteritidis en la cadena alimentaria. Lamentablemente, los controles actuales no parecen eficaces para reducir el nivel de infecciones por Campylobacter y VTEC 0157. En el futuro, las estrategias de control habrán de tener en cuenta las diferencias
epidemiológicas que existen entre diversas toxo-infecciones alimentarias zoonóticas, y utilizar métodos cuantitativos de análisis de riesgos para garantizar la aplicación de los programas que ofrezcan mejor relación eficacia/coste.

**Palabras clave**
Aves de corral - Bacterias - Campylobacter - Epidemiología - Escherichia coli - Salmonella - Toxi-infección alimentaria - Zoonosis.

**References**


