Introduction

Salmonellosis remains within the top two bacterial foodborne diseases in countries worldwide (campylobacteriosis being the other one), constituting a major international public health problem with huge industry and societal costs. In the United Kingdom (UK) the serovars *S. Enteritidis* and *S. Typhimurium* are the major isolates from human infections (1) with smaller contributions from serovars like *S. Infantis*. This is a similar pattern to European data (Fig 1) and elsewhere but novel strains are constantly emerging to cause concern, for example monophasic *S. enterica* subsp. *Enterica Serovar 1,4,[5],12:i:-. The zoonotic sources of salmonellosis have been recognized for many years. This review will discuss how, by working together, the regulatory authorities, industry, medics, veterinarians and scientists have successfully controlled this foodborne infection in the United Kingdom.
Implications for society and the poultry industry

Salmonellosis is a particular issue for the food production industry worldwide. Nowadays, especially in the developed world, people expect their food to be safe to eat and the attention of public media and the internet now ensures everyone knows about unsafe food. However, increasingly food production companies are operating globally, and the standards of food production across the world vary significantly. Food-borne outbreaks, when they occur, can have significant economic impacts on the food industry both at the points of consumption and production, with the potential to damage export status. Over the last few decades, as a result of a number of food safety issues, the food production industry in the UK has undergone huge changes to address the issue of the microbiological safety of food. These changes, linked to a well-structured and relatively stable public health surveillance capacity, has provided some excellent examples of the societal benefits of the integrated production of microbiologically safe food, especially in the prevention of salmonellosis.

The common symptoms of non-typhoidal salmonellosis is diarrhoea, fever, vomiting and abdominal cramps 12-72 hours post infection. In most cases the illness lasts 4-7 days. However, illness varies in severity and this variation is related to the dose, the serovar and the age or immune competence of the individual. In severe cases death can occur. In 2002 Adak et al., (3) reported that in England and Wales 3.6% of cases were hospitalised and 0.3% died. The reference European Union Summary Report (2012) gives an update of the prevalence for EU countries.

Figure 1: Distribution of the 10 most common Salmonella serovars in humans in the EU, 2012.


The incidence of salmonellosis in the United Kingdom is well monitored and its reporting is mandatory. In 2012 the Health Protection Agency (HPA, now Public Health England) reported 8,003 confirmed cases of salmonellosis in England and Wales (1), of which 27% were S. Enteritidis and 23% S. Typhimurium. However, community-based studies have shown that there is significant under-reporting of salmonellosis (4) such that the true level of infections is about 39,000. Santos et al. (5) estimated that the total cost of salmonellosis in England and Wales in 2011 was £6.5 million per year (£8.5/annum or $10.4/annum). However, the situation used to be much worse.

Increasing Salmonella awareness

From about 1955 to 1975 the total number of cases of salmonellosis was less than 5,000 per year and mostly due to S. Typhimurium. Although, the numbers slowly started to rise (Fig 2) no real alarm was raised until 1988 when there was 170% increase in reported disease (6) mainly due to S. Enteritidis of the phage type 4 (PT4). This phage type was already known to be associated with poultry and eggs. Epidemiological investigations quickly linked this increase to the consumption of foods containing uncooked or undercooked eggs. The Chief Medical Officer of the day published a warning to vulnerable people, including children, pregnant women, and the elderly about eating uncooked eggs. Then Edwina Currie, a junior Health Minister, announced to 10 million television viewers that “most of the egg production in this country, sadly, is now affected with Salmonella”. The poultry industry and the Ministry of Agriculture, Fisheries and Foods (MAFF) countered stating that with just 26 cases of food poisoning confirmed as being caused by eggs, the chances of infection in humans was put at 1:200 million (7). However, the general public reacted dramatically and, almost overnight, egg sales plummeted by 60%. The poultry industry was outraged. Edwina Currie lost her job (and went on to write best-selling novels). The crisis cost the UK government nearly £8 million in compensation for 400 million surplus eggs and 4 million unwanted hens (4% of the national flock).

Regulation and the poultry industry response

In response to the public outcry the government passed the 1989 Zoonoses Order in which all isolates of Salmonella from farm animals and birds, their carcasses, products, feed or surroundings were to be reported (8). This was closely followed by the 1993 The Poultry Breeding Flocks and Hatcheries Order (9). This order stated “In cases where Salmonella infection is confirmed after an investigation, the flock must be slaughtered. However, in the case of a parent broiler breeder flock alternatives are offered, which include antibiotic treatment of the parent flock or its progeny”. The order specified the regular compulsory monitoring of breeding flocks of ≥ 250 birds throughout their lifespan and hatcheries with an incubator capacity for > 1,000 eggs. Faeces and progeny at the hatcheries were tested using standardised sampling protocols and bacteriological methods. Any layer flock positive for “invasive” strains were sent for slaughter. The order also allowed for some optional measures including the voluntary Salmonella vaccination of breeding flocks and the heat treatment of feed. Despite these regulations, through 1988 to 1993, reported cases of human salmonellosis continued to steadily rise in Great Britain (Fig 3). There was a temporary fall following the 1993 Order but then another steady increase. Moreover, the Advisory Committee on the Microbiological Safety of Foods (ACMSF) has reported that egg surveys carried out in 1991 and again in 1995/96 showed no change in the prevalence (about 1% in both surveys) of Salmonella contamination of eggs at retail (10). Clearly there had been little effect on the public exposure.
By this time it became clear to the industry that the situation had become unacceptable. The scientific evidence had clearly demonstrated the link between contaminated eggs and human disease by showing that some strains of *Salmonella* (in particular *S. Enteritidis*) were adapted to colonise the oviduct and thereby contaminate eggs. But this vertical transmission was not the only source of the problem in poultry. Detailed monitoring demonstrated critical points of contamination in the environment around poultry houses and proved the role of horizontal transmission from vectors like feed, rodents and insects. Some poultry companies started taking voluntary steps to address the problem and the British Egg Industry Council (BEIC) (11), which was set up in 1986 by major organisations to represent the British egg industry, became a focussing force for the demoralised industry. By November 1998 the BEIC had established and then launched a Quality Assurance Scheme (the Lion Code) for eggs (12).

**Quality assurance and the Lion Code of Practice**

Members of this scheme are allowed to market eggs stamped with a red lion indicating they are produced to the Lion Quality Code standard. This Code makes a number of assurances and guarantees including that the hens are vaccinated, originally against *S. Enteritidis*, and more recently also against *S. Typhimurium*. The Code enables traceability of the hens, eggs and their feed, specifies levels of hygiene and the *Salmonella* testing of all flocks and eggs. Finally, there is regular independent auditing of all egg producers and packing units. The Lion Code Quality Scheme is currently used by 90% of British egg producers in independent auditing of all egg producers and packing units. The Lion Code Quality Scheme is currently used by 90% of British egg producers who are the preferred suppliers to the retail and catering industries. Today the Red Lion stamp has a huge level of brand recognition by the public and is thus a high level of consumer acceptance and trust.

In 2013, the Lion Code was revised (Lion Code 7) to include compulsory vaccination with *S. Typhimurium* (except caged flocks under veterinary vaccination with *S. Enteritidis*, and more recently also against *S. Typhimurium*. The Code enables traceability of the hens, eggs and their feed, specifies levels of hygiene and the *Salmonella* testing of all flocks and eggs. Finally, there is regular independent auditing of all egg producers and packing units. The Lion Code Quality Scheme is currently used by 90% of British egg producers who are the preferred suppliers to the retail and catering industries. Today the Red Lion stamp has a huge level of brand recognition by the UK public and is thus a high level of consumer acceptance and trust.

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**The success of the Lion Code Quality Scheme**

In 1998, at the time of the introduction of the Lion Code Scheme, there were over 14,000 reported cases of human salmonellosis in England and Wales (Fig 3). Since then there has been a year-on-year fall to just over 8,000 cases in 2012 suggesting that the Lion Code Scheme has been extremely successful. Additional evidence for this comes from the concomitant decrease in food-borne *Salmonella* outbreaks (2) and the comparison of the two surveys of human intestinal infectious disease in 1993-6 and then again 2008-9 that concluded: “The reduction in nontyphoidal salmonellosis demonstrates the success of Europe-wide control strategies, notably an industry-led *Salmonella* control program in poultry in the United Kingdom.” (14).

As further proof of the control strategy success a further survey in 2003 of UK-produced eggs at retail found a threefold reduction (from 0.99% to 0.34%) in the prevalence of *Salmonella* contamination compared with the 1995/96 survey (10).

Two key factors have been attributed to the control of salmonellosis. In 2003 in their Second Report on *Salmonella* in Eggs (14) the ACMSF stated: “There has been a sustained drop in human *Salmonella* cases since 1997. We believe that this reflects a corresponding fall in the levels of *Salmonella* in eggs. There are reasons for believing that these improvements flow from the widespread vaccination of egg laying flocks against *Salmonella* Enteritidis, combined with improved flock hygiene measures.”

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**The importance of vaccination**

Vaccination was arguably the more important factor. Vaccination of breeder flocks (2) was established in 1994, and then established for layer flocks in 1997. Initially an inactivated *S. Enteritidis PT4* vaccine was used but by 2001 a live oral *S. Enteritidis* vaccine had been launched followed in 2003 by a live oral *S. Typhimurium* vaccine. Today Lohmann surveys indicated that the majority of breeder and layer flocks in the United Kingdom are vaccinated by live, rather than inactivated, vaccines. Apart from ease of oral vaccination, live vaccines have the additional advantage of inducing a cellular immune response as well as a gut mucosal antibodies, both of which are necessary for fully effective and sustained immune protection.
Conclusions

The UK experience demonstrates the effectiveness of the Lion Code of Practice as an industry-led response to consumer demand for safer eggs. Even so it took 25 years for egg consumption in the UK to return to the "pre-Currie" levels (7). The same industry-led approach valid for the egg industry has now been adopted by the UK poultry meat industry, which has developed the Assured Chicken Production Scheme. This scheme, which uses the Red Tractor logo as a quality mark, includes the testing of every broiler flock monthly for Salmonella, enhanced biosecurity and animal welfare, and total traceability of the life of the bird.

The success of the UK strategy for controlling salmonellosis has acted as a model for the rest of Europe. Since 2000 the European Union has introduced a number of regulations aimed at reducing Salmonella in breeder, layer and broiler flocks, following similar approaches to those adopted in the UK and with the result that levels of salmonellosis are falling throughout Europe (15). Now the big challenge for the UK poultry industry, regulators, medics, veterinarians and scientists is to deal as successfully with Campylobacter.

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