The EFSA Journal (2008) 625, 1-32

A quantitative microbiological risk assessment on *Salmonella* in meat[1]: Source attribution for human salmonellosis from meat[2]

Scientific Opinion of the Panel on Biological Hazards

(Question N° EFSA-Q-2006-077)

Adopted on 24 January 2008

PANEL MEMBERS

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SUMMARY

In the present mandate EFSA was asked, by the European Commission (EC), to carry out a quantitative risk assessment and evaluate: the relative contribution of different meat categories to cases of food-borne *Salmonella* infections in humans, taking into account the occurrence of the pathogen in the food chain, risk factors, food production flows and food preparation and consumption habits. Following discussion with the EC, it was clear that QMRA was only one of several methods available for answering the ToR. In addition it was found that the questions were very broad and that data gaps would limit the possibilities for a complete answer to the questions. The WG agreed that the mandate should be pursued through focusing on different approaches for source attribution of human salmonellosis and the results obtained so far from such studies.

Different MS use different approaches for source attribution of human salmonellosis, e.g. analysis of outbreak data, analytical epidemiology, microbial subtyping, comparative exposure assessment, and structured expert opinion. Each method of source attribution has different strengths and weaknesses and addresses different points in the food chain. The choice of method is therefore dependent on the questions that need answering. Comparing and

1 Title as in the original mandate received from the European Commission

2 For citation purposes: Scientific Opinion of the Panel on Biological Hazards on a request from the European Commission on a quantitative microbiological risk assessment on *Salmonella* in meat: Source attribution for human salmonellosis from meat. *The EFSA Journal* (2008) 625, 1-32

compiling results from more than one method may provide more robust results than using only one approach.

The available data are, however, limited and sometimes not sufficient to make quantitative estimates of the contribution of meat to human salmonellosis across EU. Even where data are available they are rarely fully used to identify the main sources of human salmonellosis in a source attribution model.

In the EU, among the foodborne cases of human salmonellosis, eggs and egg products are still the most frequently implicated sources. Meat is also an important source of foodborne salmonellosis, with poultry and pork implicated more often than beef and lamb. More specific conclusions about the relative importance of specific meat categories brought into the kitchen raw, for example, fresh meat and products thereof, minced meat and meat preparations, cannot be made at present.

According to outbreak data in the EU, eggs and egg products are the foods most commonly implicated in human salmonellosis. Meat especially poultry and pork meats are also commonly involved. Outbreak data collated at the EU level and in many MS do not allow clear identification of meat categories (such as carcasses, fresh meat and products thereof, minced meat and meat preparations) involved in human salmonellosis because food have not been uniformly categorised. In addition, as information is rarely available on food handling and processing practices, it is often not possible to trace back *Salmonella* contamination to the original source (food type) or to deduce the impact of consumer handling.

Case control studies of sporadic cases of salmonellosis have identified the same foods as for outbreaks, as well as several non-food related factors. Source attribution through microbial subtyping in several MS (Denmark, Netherlands, Germany) has identified layers (eggs) as the major source of human salmonellosis. Among the meat producing animals, pigs and broilers are more important reservoirs for human salmonellosis than cattle. Such studies have not been published in other MS.

There are differences in serotype distribution in human cases in MS which may be a consequence of differences in serotype distribution and prevalence of *Salmonella* in food animals, differences in animal production, food processing, food preparation and hygiene and different food consumption patterns.

Comparative risk assessment is the only method that in principle allows the high resolution required to estimate the proportion of cases attributable to different meat categories as specified in the mandate. Nevertheless, this approach has not yet been used for human salmonellosis.

Where few or contradictory data are available, formal structured expert opinions can be an alternative option for estimating source attribution. The few formal structured expert opinions on *Salmonella* source attribution published identify eggs and poultry as the most important food sources. Other foods including red meats were also identified.

In the opinion data requirements for efficient source attribution of human salmonellosis by the different methods, are given.

Key words: *Salmonella,* salmonellosis, meat, source attribution

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BACKGROUND AS PROVIDED BY THE COMMISSION

The Commission has recently adopted Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs[3], setting down microbiological criteria for certain pathogens in specific food categories. Although several scientific opinions were considered when developing these new Community criteria, quantitative microbiological risk assessments (QMRA) at Community level were not available at that time. Outcomes of QMRA would be very helpful, when risk management options for microbiological hazards in food are considered.

According to Article 4 of Directive 2003/99/EC on the monitoring of zoonoses and zoonotic agents[4] Member States shall collect relevant and comparable data in order to identify and characterise hazards, to assess exposures and to characterise risks related to zoonoses and zoonotic agents. Furthermore, each Member State shall transmit to the Commission an annual report on trends and sources of zoonoses and zoonotic agents including data on *Salmonella* in foodstuffs (Article 9). Revision of zoonoses data collection and the zoonoses reporting manual is currently ongoing in EFSA. In this context pathogen/food categories have been adjusted in accordance with Regulation (EC) No 2073/2005, which would facilitate obtaining more accurate data for the risk assessment.

Regulation (EC) No 2073/2005 lays down two types of microbiological criteria for foodstuffs, process hygiene and food safety criteria. As regards *Salmonella*, process hygiene criteria have been set down for carcases and food safety criteria for a number of food categories including minced meat, meat preparations and certain meat products. Process hygiene criteria indicate the acceptable functioning of the process permitting certain tolerance for *Salmonella* in carcases. Food safety criteria define the acceptability of the batch and if *Salmonella* is present in any of the sample units tested, the batch has to be withdrawn from the market or, if not yet at retail level, may be submitted for further processing.

TERMS OF REFERENCE AS PROVIDED BY THE COMMISSION

The European Food Safety Authority is asked to carry out a quantitative risk assessment and evaluate:

1. The relative contribution of different meat categories, such as carcasses, fresh meat and products thereof, minced meat and meat preparations to cases of food-borne *Salmonella* infections in humans, taking into account the occurrence of the pathogen in the food chain, risk factors, food production flows and food preparation and consumption habits. A distinction between meats derived from different species, such as bovine, porcine, poultry (if possible separately broilers and turkeys) and other possible species should be considered. In particular, the impact of the intended and common use of the above-mentioned meat categories derived from different species should be taken into account as well as the impact of cross-contamination.

[3] OJ L 338, 22.12.2005, p. 1.
[4] OJ L 325, 12.12.2003, p. 31.

2. The impact of main factors along the food chain affecting the prevalence, growth and transmission of *Salmonella* in the above-mentioned meat categories and the related risk of human illnesses, in the light of prevalence data and epidemiological data to be supplied by the Member States.

This point should be further discussed when initial results of the first point are available.

Following discussion with the Commission, it was decided that it would be preferable if the two ToRs were dealt with in separate documents, thus this Opinion will only address ToR 1.

ACKNOWLEDGEMENTS

The European Food Safety Authority wishes to thank the members of the Working Group for the preparation of this opinion: Pierre Colin, Tine Hald, Arie Havelaar, Antonio Martinez López, Birgit Nørrung (Chair), Sarah O'Brien, Terence Roberts and Mieke Uyttendaele. Assistance to the working group from Sava Buncic, Danilo Lo Fo Wong, and Wilfrid Van Pelt is also acknowledged.

ASSESSMENT

1 Introduction

1.1 Interpretation of Terms of Reference

Risk assessment for microbiological hazards in foods is defined by the Codex Alimentarius Commission, (CAC, 1999), as a scientifically based process consisting of the following components; hazard identification, exposure assessment, hazard characterisation and risk characterisation. Quantitative microbiological risk assessment (QMRA) is a tool that can be used for several different purposes. Performing a QMRA can however, be rather time consuming, and sometimes impossible, if sufficient data are not available. Until now QMRA has only been used to a limited extent by risk managers at both the national and international level and there are still many challenges in communication between risk assessors and risk managers in relation to possibilities and applicability of QMRA.

In the present mandate an opinion concerning a quantitative microbiological risk assessment on *Salmonella* in meat has been requested by the European Commission (EC). More specific according to ToR 1 "The EFSA is asked to carry out a quantitative risk assessment and evaluate: the relative contribution of different meat categories, such as carcasses, fresh meat and products thereof, minced meat and meat preparations to cases of food-borne *Salmonella* infections in humans, taking into account the occurrence of the pathogen in the food chain, risk factors, food production flows and food preparation and consumption habits. A distinction between meats derived from different species, such as bovine, porcine, poultry (if possible separately broilers and turkeys) and other possible species should be considered. In particular, the impact of the intended and common use of the above-mentioned meat categories derived from different species should be taken into account as well as the impact of cross-contamination." In addition (ToR 2) "The EFSA is asked to carry out a quantitative risk assessment and evaluate: the impact of main factors along the food chain affecting the prevalence, growth and transmission of *Salmonella* in the above-mentioned meat categories and the related risk of human illnesses, in the light of prevalence data and epidemiological data to be supplied by the Member States".

The mandate was discussed with representatives from the EC at several WG meetings and it was emphasised by the WG that QMRA was only one of several methods available for answering the ToR 1. In addition it was found that the questions were very broad and that data gaps would limit the possibilities for a complete answer to the questions particularly for comparative QMRA, which in theory, would be the optimal way for answering ToR1. The WG agreed that the mandate should be pursued through focusing on different approaches for source attribution and the results obtained so far from such studies. It is important to bear in mind that not all cases of human salmonellosis are foodborne since other transmission routes like environmental exposure, direct animal contact and human-human transmission also exist. In the present opinion however, source attribution is focused on meat and meat producing animals although eggs and other sources are also mentioned. Data requirements for developing *Salmonella* attribution models in all EU countries or at the EU-level are discussed. Following from discussion with the Commission, it was agreed that only ToR 1 should be addressed initially. Upon the completion of this task, further discussions with the Commission will take place before addressing ToR 2.

2 Human salmonellosis

2.1 Incidence in the European Union

In 2005, a total of 170,497 cases of human salmonellosis were reported to the Basic Surveillance Network (BSN) from 22 EU MS (168,929 cases), Iceland and Norway with Germany reporting 31% of the total. Countries indicated that 97% of all cases were laboratory-confirmed. Overall the incidence in the EU was 40.0 per 100,000 population. Despite a general decrease compared with 2004, some MS experienced an apparent increase: Czech Republic, Denmark, Estonia, Hungary, Latvia and Lithuania. This may be the result of improved surveillance (particularly in the new MS), or the occurrence of foodborne outbreaks rather than sporadic cases. The highest number of cases occurred in the age group 0-4 years (21% of all cases), followed by the 5-14 and 25-44 year olds (both 15%). Compared with 2004, numbers of cases in the age group 45-64 increased in 2005 (13% of cases). A peak in the number of reported cases was evident in the late summer/autumn months.

Twenty-two countries (21 EU MS and one non-MS) reported 98,882 cases of salmonellosis to Enter-net. For Belgium, Finland and Greece this was the only source of information for human cases of salmonellosis. As cases are reported to Enter-net only from national reference laboratories in each individual country, the total number of cases reported through Enter-net is usually smaller than the total number of cases reported through the BSN. Thus incidence rates are not calculated using Enter-net data since they only represent a fraction of the total number of cases.

S. Enteritidis was the most frequently reported serovar in both BSN and Enter-net, followed by *S.* Typhimurium. Twenty-one MS and Iceland reported 86,536 (52%) *S.* Enteritidis cases and 15,058 (9%) *S.* Typhimurium cases to BSN, whereas Enter-net received reports of 69,348 (69%) *S*. Enteritidis cases and 12,844 (13%) *S.* Typhimurium cases. The ranking of serovars is based on the sum of the reported serovars. *S.* Bovismorbificans scored high behind *S.* Enteritidis, as did *S.* Typhimurium and *S.* Infantis due to a large outbreak in Germany. *S.*

Enteritidis and *S.* Typhimurium were the most frequently reported in both BSN and Enter-net, but the proportions are higher in the Enter-net data where those two serovars account for 82% compared with 61% in the BSN data. In 34% of cases in the BSN dataset the serovar was unknown (not reported).

When contamination of a food is common, as occurred with *S*. Enteritidis in eggs and poultry, serovars isolated from cases of salmonellosis are identical to those occurring in the food. When strict hygienic measures are implemented, the serovars isolated from animal feed and animals often differ from those causing human salmonellosis.

Looking at the level 3 data from the Community Summary Report on Trends and Sources of Zoonoses, Zoonotic agents and Antimicrobial Resistance and Foodborne Outbreaks in the European Union in 2005 (CSR) (EFSA 2006), it appears that there are differences in the distribution of serotypes from human salmonellosis in different MS. This may be a consequence of differences in serotype distribution and prevalence of *Salmonella* in food animals, differences in animal production, food processing, food preparation and hygiene and or different food consumption pattern.

2.1.1 Travel related cases

From the CSR, overall, half of the reported cases of human salmonellosis in the EU were domestically acquired, and only 7% of the cases were acquired abroad. For 43% of cases there was no information on whether the cases were acquired domestically or abroad - hence that may not represent a true picture. Sweden and Finland had the highest proportion of imported cases (cases coming from outside a given Member State). (The data for The Netherlands are incorrectly presented in the CSR).

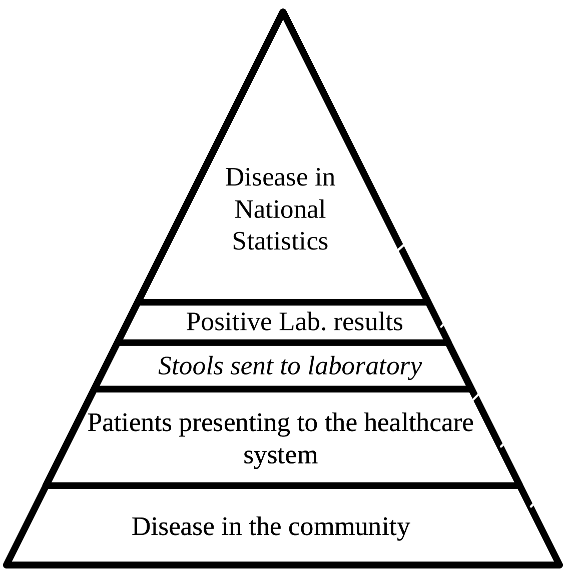
In Sweden, more detailed studies on the epidemiology of travel-associated non-typhoidal salmonellosis have been performed (Ekdahl et al., 2005; de Jong and Ekdahl, 2006a,b). Relative risks for travellers were highest when travelling to East Africa or the Indian subcontinent, but in absolute numbers, most cases occurred among travellers to Southern Europe and the Eastern Mediterranean. *S.* Enteritidis was the most common serotype in European travellers, but less common in travellers to other continents. The authors also assessed the risk per individual European country, which varied between 0.2 (Norway) to 129 (Bulgaria) per 100,000 travellers. By comparison with reported cases in the resident population in all European countries, an “underdetection index” was constructed. This index was then used to estimate the incidence of salmonellosis independent of the national reporting systems. Underlying these calculations is the assumption that the risks to Swedish travellers is proportional to the risk of the resident population, hence differences in eating habits, hygiene, immunity etc. are ignored. The authors argue that these biases are smaller than those introduced by differences in surveillance systems. It was also demonstrated that the risk of salmonellosis (all serotypes) for travellers correlated well with the prevalence of *Salmonella* in laying hen flocks as reported in the EU baseline study in 2004-2005.

2.2 Underreporting of salmonellosis

Most ongoing surveillance schemes for foodborne disease depend upon symptomatic patients consulting with, or presenting to, a primary care physician. Without this step the illness is unlikely to be recorded in any official statistics. The loss of data at various points along the surveillance chain from patient, through laboratory tests, to official statistics is generally described as a pyramid (Figure 1). Disease in the community forms the base of the pyramid while those cases that reach official statistics form the apex.

There have been relatively few attempts to calibrate *Salmonella* surveillance data at national surveillance institutes, but some researchers have attempted to equate disease in the population to what appears in official statistics. In a three year study of infectious intestinal disease (IID) in England in the mid 1990s the investigators determined that for every laboratory-confirmed case of *Salmonella* reported to national surveillance, 3.8 cases occurred in the community (Wheeler et al., 1999). This means that national statistics on laboratory-confirmed salmonellosis in England should be multiplied by 3.8 in order to describe better the community burden of salmonellosis. There are few similar examples from other countries. In the Netherlands the multiplier is approximately 13.4 (calculation based on Kreijl et al., 2006) whilst in the US it was estimated to be 38.6 (Voetsch et al., 2004). Surveillance systems "eavesdrop" on the healthcare system, and their organisation in MS varies considerably. For example, the surveillance system in the UK is highly centralised whilst those in MS like Germany and Spain are highly federalised. How differences in the organisation of surveillance might impact on reporting efficiency has not been investigated in a systematic way across the EU. It is likely that there is considerable variation in reporting efficiency across MS. The data items that are available to describe disease burden, and hence contribute to source attribution, are lacking in many MS (Table 1).

Figure 1: **Surveillance pyramid showing the multipliers for *Salmonella* in England and the Netherlands**



	England Based on IID*	**Netherlands Based on Sensor****
Disease in National Statistics	1	1
Positive Lab. Test	1.2	NA
Stools to Lab.	*NA*	*NA*
Patients Presenting to Physician	2.3	4.9
Disease in the Community	3.2	13.9

Notes: *IID = Infectious Intestinal Disease Study; **Sensor & Netherlands Institute for Primary Health Care (NIVEL) Studies; NA = not available

Table 1: **Data items for source attribution using outbreak data for human salmonellosis and their availability at European level**

Data item	Available at European level?
Total number of cases of laboratory-confirmed non-typhoidal salmonellosis	Yes
Multiplier to estimate the total population burden of salmonellosis	No - only for certain MS
Proportion of *Salmonella* cases that are foodborne	No - only for certain MS
Number of cases of foodborne salmonellosis acquired abroad (i.e. outside the EU)	No
Number of cases of foodborne salmonellosis that present to a primary care physician	No
Number of cases of foodborne salmonellosis that present to hospital	No - although limited data available from outbreaks
Number of foodborne *Salmonella* deaths	No - although limited data available from outbreaks
Total number of foodborne outbreaks of non-typhoidal salmonellosis	Yes

Recently, serological examination of population-based, age-stratified random serum samples from the Danish population (predominantly from Copenhagen) was undertaken to detect the presence of antibodies against *Salmonella* (Simonsen et al., 2007). By combining the observed seroprevalence with data on the decay rate of antibodies, it was possible to estimate the incidence of *Salmonella* infections. The data suggested that the incidence of *Salmonella* infections increased from 13 per 1000 person-years in 1983 to 217 in 1999 with a sharp rise between 1992 and 1999. By comparison with reported laboratory-confirmed cases, multipliers in the order of 150-300 were estimated. These values are much higher than multipliers based on clinical cases as discussed above, suggesting that many infections are not associated with illness.

3 *Salmonella* in animals and food

Available data on *Salmonella* in animals and food in the EU can be found in the CSR 2005 (EFSA 2006). The situation worldwide was reviewed by D'Aoust (2000) and SCVPH (2003).

3.1 Salmonella *in animals*

Many countries have *Salmonella* control or surveillance programmes in place for a number of animal species. Data are, however, most often not comparable between countries because of differences in sampling level and analytical methods.

In 2004-2005, a EU-wide fully harmonised *Salmonella* baseline study was conducted on commercial large-scale laying hen holdings with at least 1,000 laying hens in the flock (EFSA, 2007). Before this baseline study, few surveys had estimated the *Salmonella* prevalence in laying hens at the national level. Such surveys are affected by the nature of the study design (diagnostic test, sample size and sample material, the number of samples tested, the type and size of holdings or flocks studied, the type of prevalence studied, and the age of the tested animals. Comparison of such survey results is therefore impossible. In the above mentioned baseline study, the EU weighted prevalence for *Salmonella* spp. in holdings with more than 1,000 laying hens was 30.7% but ranged from 0 up to 79.5%.

In 2005-2006 a EU-wide baseline survey was carried out to determine the prevalence of *Salmonella* in commercial flocks of broilers with at least 5,000 birds (EFSA, 2007). The overall Community observed prevalence of *Salmonella*-positive flocks was 23.7%, but varied widely amongst the MS, from 0% to 68.2%. A total of 11.0% of the broiler flocks was estimated to be positive for *S.* Typhimurium and/or *S.* Enteritidis, the two most common serovars found in *Salmonella* infections in humans. The MS-specific observed flock prevalence of *S*. Enteritidis and/or *S.* Typhimurium also varied greatly from 0% to 39.3%. The five most frequently isolated *Salmonella* serovars from broiler flocks in the EU were, in decreasing order, *S.* Enteritidis, *S.* Infantis, *S.* Mbandaka, *S.* Typhimurium and *S.* Hadar. All these serovars, with the exception of, *S.* Mbandaka, are frequent causes of *Salmonella* infections in humans. The serovar distribution varied amongst the MS, many of the MS having their own predominant pattern.

3.2 Salmonella *in food*

Outbreaks of salmonellosis have been associated with a variety of foods including eggs, poultry, red meat but also other food stuffs such as chocolate confectionary, milk and milk products, salads, fruits and vegetables, fish and fishery products, etc (Hughes et al. 2007, Bell and Kyriakides 2002). Data from the EU on *Salmonella* in food can be found in the CSR 2005 (EFSA 2006). An impression of the situation worldwide can be found in D'Aoust (2000) and SCVPH (2003). In the present scientific opinion the focus was put on the prevalence of *Salmonella* in meat. Some data with regard to contamination of eggs were also included as eggs are generally accepted as the most important source of human salmonellosis.

No single harmonised scheme has been agreed upon for monitoring the occurrence of *Salmonella* in foodstuffs. However, the *Salmonella* criteria laid down by the Commission regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs provide some guidance for sampling and testing. Thus the regulation includes food safety criteria for *Salmonella* in minced meat and process hygiene criteria for *Salmonella* on carcases of pigs, ruminants and poultry carcasses. Nevertheless, there are still differences in the sampling schemes and analytical methods, as well as the type of animals, foodstuffs selected for analyses, between MS. In addition there are many different purposes for sampling (monitoring, control, research etc) and this is not necessarily appearing from the individual country reports. Therefore, results are not comparable between MS and comparison between years within the same country should be made with caution.

3.2.1 Eggs and egg products

Eggs can become contaminated with *Salmonella* as a result of infection of the oviduct or by faecal contamination. Control of *Salmonella* in the table egg sector is generally by monitoring and control in breeder and layer flocks. *Salmonella* was reported in fresh eggs, raw egg at processing and at retail level at levels similar to those in previous years (below 3%, one exception, 6%).

In raw materials for egg products, one MS reported 11.7% positives although generally very few positives were reported. *S.* Enteritidis is known to be the dominant serotype.

3.2.2 Poultry meat and products thereof

In 2005 a number of MS monitored *Salmonella* in poultry e.g. in broiler meat at different steps in the production line. Denmark, Finland, Ireland, Sweden and Norway have had programmes to control *Salmonella* in broilers for several years, with Sweden, Finland and Norway reporting very low levels of *Salmonella* over the last five years. Despite some fluctuations, a slight decrease can be observed for other countries. However, compared with 2004, increased numbers of positive samples were observed at slaughter in Italy and Spain, and at processing in Belgium, and from previously low numbers in Denmark.

Most countries providing data on *Salmonella* in fresh broiler meat reported substantial numbers of positive samples: at slaughter from 5.7-9.1%, at processing up to 21.5%, although some MS reported no positives and at retail 2.2% to 18.2%. In samples of broiler meat products that were not ready-to-eat, nine of the 10 reporting MS found *Salmonella* positive proportions (1.6% to 16.6%). In ready-to-eat (RTE) broiler products 3 of 9 MS reported positive samples including one at 11.1%.

The percentage of positive samples in fresh turkey meat varied from zero to 11.0%, and up to 5% in RTE turkey meat products.

Salmonella contamination of fresh duck ranged from 15.0 to 39.0%, and 10% in fresh geese meat in one MS.

3.2.3 Pig meat and products thereof

Whilst *Salmonella* positive samples were found in a relatively high proportion of pig meat, six of 20 reporting countries found none. At slaughter proportions of positive samples ranged from 0 to 9.3% and at the processing plant from 0 to 18.4%.

In 15 MS *Salmonella* in non-RTE products of pig meat origin ranged from 0.3 to 12.5% and generally low percentages in RTE meat products. Positives were reported for RTE minced meat and meat preparations.

Data on serovars were incomplete, but *S.* Typhimurium was the most common.

3.2.4 Bovine meat and products thereof

Monitoring programmes also exist for bovine meat in certain MS. In general, proportions of positive results in bovine meat were low throughout 2001-2005, at about 1% or below, with a few exceptions.

In 16 countries providing information on *Salmonella* in fresh bovine meat in 2005 the proportion of positive samples was below 0.6% in fresh meat at slaughter, processing- and cutting plant, except one with 6.3% of samples at slaughter positive. At retail occasional higher percentages of positives were reported (8.3%).

Minced meat, meat preparations and meat products of bovine origin, ready-to-eat and non-ready-to-eat, generally yielded low proportions of positives, including occasionally minced meat or meat preparations intended to be eaten raw.

S. Typhimurium was the most common serovar, followed by *S.* Dublin and *S.* Enteritidis.

3.2.5 Sheep meat and products thereof

Despite worldwide consumption, lamb, sheep meat, mutton, and their products have rarely been associated with human salmonellosis (D'Aoust, 2000). There are few systematic data on the prevalence of salmonellae in sheep or sheep meat in the EU. In a recent survey from France, however, less than 1% of sheep carcasses at slaughter were reported positive for *Salmonella* (DGAL, 2007).

One of the largest sheep producers, New Zealand, reported that in 1996, a new strain of *S.* Brandenburg caused abortion in sheep, and spread to other stock including cattle, horses, deer, and pigs. It also spread into the environment and caused human salmonellosis, especially among farm workers and their families (Clark et al., 2004).

4 Meat consumption data

Different consumption patterns are one of the factors that can lead to different exposure in different MS. As appears from data extracted from Eurostat database (Table 2), the consumption of meat from cattle, pigs, poultry and sheep differs among countries. In all countries however, pork meat is eaten in greater amounts than beef and sheep but varying from 63.5 kg/person/year in Spain to only 25.3 kg/person/year in UK. In Greece there is a very high consumption of sheep at 12.4 kg/person/year compared to from 0.2-6.0 kg/person/year in other countries.

Table 2: **Examples of meat consumption in the EU (2002[a])**

Country[b]	**Consumption (kg/person/year) [c]**			
	Beef	**Pork**	**Sheep and goats**	**Poultry**
Austria	18.4	55.4	1.16	17.5
Belgium	21.8	51.1	1.82	20.8
Czech Rep	-	-	-	2.3
Denmark	26.1	57.7	1.11	22.4
Finland	17.8	31.9	0.2	15.4
France	27.3	35.8	4.38	24.2
Germany	12	54	1.04	17.2
Greece	17	27	12.4	19
Ireland	16.8	36.5	5.11	29.5
Italy	24.1	37.7	1.49	17.9
Lithuania	10.2	26.6	0.23	12
Luxembourg	30.8	44	-	11.2
Malta	27.5	29.9	1.74	-
Netherlands	18.9	41.7	1.41	22.3
Portugal	16.4	43.1	3.51	30.7
Spain	15	63.5	5.51	39
Sweden	23	32.2	1	14.2
UK	20.1	25.3	6	28.5

a Data extracted from Eurostat database on "Gross human apparent consumption of main food items": http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,45323734&_dad=portal&_schema=PORTAL&screen=welcomeref&open=/agric/food/food_ch&language=en&product=EU_MAIN_TREE&root=EU_MAIN_TREE&scrollto=172

b No data available for Member States not included in the table

c According to Eurostat, the figures are calculated from supply balance sheets of agricultural products. Human consumption is defined as quantities of products made available for human consumption in all forms: quantities consumed without further processing and quantities supplied by the distributive trades and the food industry. Meat includes fresh meat as well as all meat products and preparations.

5 Source attribution and source attribution studies on human salmonellosis within the European Union

Foodborne sources of *Salmonella* include a wide range of domestic and wild animals and a variety of foodstuffs including food of both animal and plant origin. Transmission typically occurs when the organisms are introduced into the food chain via faecal contamination. Despite hygienic precautions during slaughtering and dressing carcasses are occasionally contaminated with faecal material. During cutting and e.g. mincing, this contamination can be spread into fresh meat cuts and meat preparations. Similarly, contamination of raw milk, water, vegetables and fruits and even chocolate can often be traced back to original faecal contamination during milking on farms, contact with manure or faecally contaminated waste water or faecal droppings from birds etc. If present, *Salmonella* can survive for a prolonged period in the environment and can contaminate food production or food preparation areas. Salmonellae are able to multiply in many foods e.g. stored at inadequate temperatures resulting in, increased numbers in foods and possible human outbreaks. In addition to raw ready-to-eat foods, cooked foods have also been implicated in outbreaks of salmonellosis either after inadequate cooking or through cross contamination from raw food. The organism may also be transmitted through direct contact with infected animals and environments / surfaces contaminated with faecal matter.

Several approaches to source attribution exist (Batz et al., 2005). These are outbreak investigations, analytical epidemiology, microbial subtyping, comparative exposure assessment and expert opinions. The results of different studies on source attribution of human salmonellosis are given below.

5.1 Outbreaks

Having developed an estimate of the burden of salmonellosis in the community, one way of trying to assess the proportion that is likely to be foodborne, and the foods implicated in causing human disease is to use data from outbreak investigations. A major advantage is that these data are observed at the public health endpoint.

Since 2004, the European Food Safety Authority has collected data on foodborne outbreaks in all member states. In 2005, 23 MS reported 5,311 foodborne outbreaks involving a total of 47,251 people. *Salmonella* was responsible for 63.6% of all reported outbreaks and egg products and broiler meat were the most frequently implicated vehicles of the infection. Applying the method developed in the UK on a European scale might provide valuable information on the major sources of human illness in the EU. To develop a source attribution model using outbreak data there needs to be good data on cases and outbreaks of salmonellosis and, specifically, on the food vehicles that have been implicated in outbreak investigations. Although such data are collated at EU level they are very incomplete and imprecise, especially concerning meat types. Since the quality (i.e. completeness, representativeness) of the foodborne disease outbreak data varies greatly between MS, it makes interpretation difficult and generalisations questionable.

Food vehicles linked to outbreaks of *Salmonella* have been summarised previously by D'Aoust (2000), SCVPH (2003), O'Brien et al., (2006) and Hughes et al. (2007). Eggs, egg products, broiler meat and some red meat, especially pork, are consistently identified in foodborne outbreaks of salmonellosis. Table 4 summarises the food vehicles from outbreaks of salmonellosis reported in the EU in 2005. Of 3,406 *Salmonella* outbreaks reported in the EU, meat products were implicated as vehicles in 179, but in the largest category (meat and offal unspecified) the animal origin of meat/offal implicated was unknown (Table 3).

Table 3: ***Salmonella* Outbreaks reported in the EU in 2005[a] related to meat and meat products. Data extracted from EFSA (2006)**

Animal species		**Number of reported outbreaks**
Meat and offal (unspecified)		**78**
	Unspecified	54
	Hotdog	1
	Salami	1
	Mixed meat	2
	Mixed meat product	1
	Minced meat	6
	Minced meat balls	1
	Raw meat	2
	BBQ	1
	Kebab	8
	Liver	1
Broiler/chicken		**69**
	Unspecified	45
	Roast	10
	Product	5
	Kebab	2
	Soup	2
	Pepper chicken	2
	Nuggets	1
	Breast	1
	Chicken and bowels	1
Turkey		**12**
	Unspecified	9
	Roast	1
	Cutlets	1
	Sausage	1
Pig		**11**
	Unspecified	8
	Meat preparation	1
	Shashlik	1
	Roast hog	1
Beef		**6**
	Unspecified	3
	Steak	1
	Raw/carpaccio/tartare	2
Lamb		**2**
Duck		**1**
Total		**179**

a excluding data for France as this was reported in aggregated form.

In two reviews of 1,426 foodborne general outbreaks of infectious intestinal disease (IID) in England and Wales between 1992 and 1999, 20% were associated with the consumption of poultry (Kessel et al., 2001) and 16% were linked with the consumption of red meat (Smerdon et al., 2001). In the poultry-associated outbreaks, chicken was implicated in almost three-quarters of these outbreaks, turkey in over a fifth and duck in 2% of outbreaks. The organisms most frequently reported were *Salmonella* (30% of outbreaks), *Clostridium perfringens* (21%) and *Campylobacter* (6%). Over 7000 people were affected, with 258 hospital admissions and 17 deaths. In the red meat-associated outbreaks over 5,000 people were affected, with 186 hospital admissions and nine deaths. Beef (34%) and pig meat (32%) were the most frequently implicated meat types, with lamb implicated in 11% of outbreaks. *Salmonella* was the second most frequently identified organism in these outbreaks (34.3%). However, in both reviews there was scant information about whether or not the implicated meat had been ground up or not.

Adak et al. (2005) used data from outbreaks to attribute foodborne disease to source in England and Wales. Table 4 shows the risks associated with various types of meat. It is noteworthy that in this analysis the most important cause of UK-acquired foodborne disease was contaminated chicken (398,420 cases, risk = 111; case-fatality rate = 35, deaths = 141). Red meat (beef, lamb, and pork) contributed heavily to deaths, despite lower levels of risk (287,485 cases, risk = 24, case-fatality rate = 57, deaths = 164). In these analyses it was impossible to determine whether or not the contaminated meat had been ground up or not. It should also be noted that the data presented in Table 4 include all foodborne bacterial pathogens, not just *Salmonella* spp.

Table 4: **Estimated risks associated with types of meat, England and Wales, 1996-2000 (Adak et al, 2005)**

Food group/type	Disease risk*	Risk ratio	Hospitalisation risk†	Risk ratio
Poultry	104	947	2,063	4,584
Chicken	111	1,013	2,518	5,595
Turkey	157	1,429	645	1,433
Mixed/unspecified	24	217	852	1,893
Red meat	24	217	102	227
Beef	41	375	153	339
Pork	20	180	93	208
Bacon/ham	8	75	39	86
Lamb	38	343	128	285

Notes: * = Cases/1 million servings; † = Hospitalisations/1 billion servings; The lowest disease and hospitalisation risks were for cooked vegetables, which were used to calculate disease risk ratios and hospitalisation risk ratios for other food types.

Extrapolating information from outbreak datasets in an attempt to describe foodborne *Salmonella* burden is not straightforward. A major limitation is investigation bias. Large outbreaks, outbreaks associated with the food service and institutions, and outbreaks that have short incubation times or cause serious disease are more likely to be investigated and reported (O'Brien et al., 2002). Consequently, the data may not reflect what occurs in sporadic cases.

A second major limitation is that it is assumed that the relative pathogen-specific contribution of each food type to both sporadic and outbreak associated disease is similar and, therefore, that outbreak experience can be generalised to sporadic disease. However, certain vehicles may be more likely to be implicated in outbreaks than others, especially if investigators preferentially collect data on the types of food perceived as high risk, or when laboratory methods vary in sensitivity according to food type. A systematic vehicle detection bias might underestimate the contribution and risks attributable to foods less commonly implicated in outbreak investigations.

A third limitation is that in many outbreaks it is not possible to find an etiological agent and/or identify a source of infection. D'Aoust (2000) published a detailed overview of *Salmonella* outbreaks but published outbreaks are a biased fraction of all outbreaks. In a review of 1,763 outbreaks of food-borne disease in England and Wales, in which food vehicles reported to a systematic surveillance system were compared with those published in the peer-reviewed literature, publications in the peer-reviewed literature favoured the unusual food vehicle or novel event (O'Brien et al., 2006). This is not entirely surprising given the mission of peer-reviewed journals but it might also influence expert judgments, and hence expert reviews.

Although source attribution using outbreak data is a promising approach, there are large gaps in the datasets available at EU level. Despite substantial data on foodborne outbreaks, not all information contributes to gaining insight into the importance of various foodborne pathogens, outbreak settings and contributing factors at a Community level because almost three quarters of all foodborne outbreaks are reported in aggregated form. Such data still provide information on the total number of people involved, hospitalisations and deaths, but not the number of human cases that can be assigned to an individual source and location.

A major step forward would be to work towards a minimum dataset to be collected in each MS, including harmonisation of food categories, and to encourage the reporting of disaggregated data to EFSA. To make this possible, it is essential that surveillance experts in each MS be closely involved with the analysis and subsequent interpretation of the dataset, since they are best placed to understand the biases in their own, and hence the aggregated data.

The detail in the data currently gathered at the European level is not sufficient to allow this approach to answer the ToR.

5.2 Attribution of sporadic cases of human salmonellosis through analytical epidemiology

Case-control studies are commonly used for identifying risk factors for sporadic human infections. They are a valuable investigative tool, providing rapid results at relatively low cost, but caution should be exercised unless results are confirmed by other evidence. Case-control studies are hypothesis-driven. Sample sizes are determined to detect associations for major hypothesised risk factors. The more hypotheses tested, the greater the likelihood that statistical associations between a particular food exposure and disease will be detected by chance. Each study delivers a snapshot of the epidemiology of disease at a point in time for a defined population. To enable source attribution from analytical epidemiology requires not only knowledge of risk factors but also population-attributable fractions i.e. the proportion of cases in any study that can be explained by exposure to a particular risk factor. For example, in a case-control study involving 100 case-patients there might be a very strong statistical association between consumption of turkey and development of salmonellosis. However, if that strong statistical association explains only 4 of 100 cases the population-attributable fraction (PAF) is very small and suggests that another major risk factor has not been identified.

Table 5 summarises the results of case-control studies of sporadic salmonellosis, published in the peer-reviewed literature since 1995, in which meat was identified as an independent risk factor for illness (Medline search terms = "salmonella" and "sporadic" and "case-control study"). Of 49 studies identified by the literature search 25 were case-control studies of sporadic salmonellosis. Three studies were focused on domestic hygiene practices, two on risk factors for antimicrobial resistance, one on the risks associated with exotic pet ownership and one on the risks of sequelae following *S*. Typhimurium infection.

It is immediately apparent from Table 5 that (a) the studies vary considerably in size, reflecting the hypotheses to be tested; (b) some of the studies are directed at specific population sub-groups e.g. hospitalised patients or young children; (c) the food vehicles independently associated with illness have fairly general descriptions and (d) not all investigators have calculated Population Attributable Fractions (PAFs), nor are data presented in the paper that would enable the calculations to be made. Where PAFs have been presented the proportion of cases explained in each study varies considerably and they can be calculated for only a small number of foods for the small number of pathogens studied with these methods. It may be difficult to generalise PAFs for individual foods because food production patterns and consumer preferences change from country to country and with time (Adak et al., 2005). Corroborative evidence to support identified associations between disease and food consumption in studies of sporadic disease is usually lacking.

Table 5: **Summary of case-control studies of sporadic salmonellosis published since 1995 in which meat was implicated as an independent risk factor**

Year(s) of study	Country	*Salmonella* serotypes investigated	Cases: Controls	Meat implicated as an independent risk factor?	Population Attributable Fraction	Reference
2002-2004	US (8 FoodNet Sites)	Non-typhoidal *Salmonella*	442: 928 infants <1 year of age	Meat - type not specified	8% overall	Jones et al., 2006
2002-3	US (8 FoodNet Sites)	Highly resistant *Salmonella* Newport-MDRAmpC	215: 1154	Uncooked ground beef	4.6%	Varma et al., 2006
2002-2003	US (8 FoodNet Sites)	*S*. Enteritidis	218:742	Chicken prepared outside the home		Marcus et al., 2007
2002-3	Netherlands	*S*. Typhimurium	232: 3409	Undercooked meat - type not specified	7%	Doorduyn et al., 2006
2001-2002	Australia	*S*. Birkenhead	111: 234	Food from a fast food chicken chain	Not calculated	Beard et al., 2004
2000	Spain	Non-typhoidal *Salmonella*	21: 84 hospitalised children <3 years old	Meat products - type not specified	Not calculated	Bellido Blasco et al., 2007
1996-1997	US (5 FoodNet Sites)	*S*. Enteritidis	182: 345	Eating chicken outside of the home	35% (all cases); 28% (domestically-acquired cases)	Kimura et al., 2004
1996	France	*S*. Typhimurium	101: 101 children < 14 years of age	Undercooked ground beef	35%	Delarocque-Astagneau et al., 2000
1994-1995	Spain	Non-typhoidal *Salmonella*	44: 69 Children aged 1 to 7 years (Note: controls were laboratory-confirmed cases with enteric viruses or *Campylobacter*)	Minced meat -type not specified	Not calculated	Bellido Blasco et al., 1998
1993-1994	Norway	Non-typhoidal *Salmonella*	94: 226	Poultry purchased abroad		Kapperud et al., 1998

Few investigators publish a complete list of food vehicles included in case-control studies, tending to concentrate on those statistically significant in single risk variable analyses and subsequent multivariable analyses. Therefore, it is impossible to know if the case-control studies in which minced meat was not identified as a risk factor actually included minced meat amongst the hypothesis to be tested i.e. minced meat might not have been implicated statistically because it was not included in the questions presented to cases. The study by Jones et al., (2006) is noteworthy because, amongst the hypotheses to be tested, was the risk to children from riding in a shopping cart next to meat or poultry. Not only was there a strong statistical association between riding in a shopping cart next to meat or poultry and developing salmonellosis, but the PAF was 11.3% and was larger than that for actually eating meat!

Case-control studies are prone to several types of bias. Case and control selection, participation and individuals' recall can all bias results. Given the time delays inherent in patients presenting to a healthcare system and diagnosis of salmonellosis what is intended as an explicit food history might, in fact, be an expression of food preferences rather than actual exposures (Hardnett et al., 2004). The choice of exposure window is also critical. Many investigators choose the maximum incubation period, which poses a problem when studying common exposures since the likelihood of detecting a difference in exposures between cases and controls is limited by high exposure frequencies in both groups (Hardnett et al., 2004). To overcome this Mølbak and Niemann (2002) used the most relevant incubation period in their study of sporadic salmonellosis in Denmark. By reducing a 5-day exposure window to 1 day they detected an increased risk of illness associated with egg consumption, which was a common food exposure. Where food exposures are common, using a shorter time window in case-control studies of sporadic illness might be desirable. Community guidelines for analytical and descriptive epidemiological studies of foodborne illness would be helpful and improve comparability of results.

One potential source of bias that is rarely considered in case-control studies is acquired immunity. Unwitting inclusion of immune controls in a case-control study will tend to reduce statistical associations towards the null hypothesis (i.e. under-estimate the impact of an exposure on illness) if immunity is present and protective. Immune controls may be consumers of food contaminated with *Salmonella* spp. but are no longer susceptible to it. None of the studies above included consideration of the immune status of controls but, given the recent data from Denmark that suggests that most *Salmonella* infections are asymptomatic (Simonsen et al., 2007), this needs to be tackled in future studies.

Given the paucity of information on meat food vehicles, case-control studies of sporadic salmonellosis are not sufficiently detailed to allow this approach to answer the ToR.

5.3 Attribution of human salmonellosis through microbial subtyping

The principle of the human illness attribution method based on microbial subtyping is to compare (sub)types of isolates obtained from animal and food samples with those obtained from human patients, i.e. the closer the resemblance of animal and food isolates with human isolates, the greater the likelihood that these were the sources of the infection. For a number of the more common types of foodborne pathogens, the discriminatory level of isolate characterisation needs to be increased in order to justify assigning human illness to a source. For this purpose, a number of microbial subtyping methods are currently available. These methods involve characterisation of the pathogen by different pheno- or genotypic typing methods (e.g. serotyping, phage typing, antimicrobial susceptibility testing, pulsed-field gel electrophoresis and sequence-based subtyping).

Microbial subtyping is extensively used for tracking outbreaks to source, and to identify diffuse outbreaks, but has been applied as an attribution method only in the Netherlands (Van Pelt *et al.*, 1999) and in Denmark (Hald et al., 2004). Although the basic idea behind the two methods is similar, the approaches differ with regard to the statistical methods applied and the number of parameters in the model. The Dutch approach compares the number of reported (domestically acquired, sporadic) human cases caused by a particular *Salmonella* type with the relative occurrence of that type in the animal-food sources. Results of attribution modelling for the Netherlands are shown in Table 6.

Throughout 1994-2005, eggs and pork were the two most important sources of human salmonellosis in The Netherlands, accounting for up to two-third of all cases in 2003. The attribution of the various sources was relatively stable.

Table 6. **Estimated contribution (%) of different reservoirs to laboratory confirmed salmonellosis in the Netherlands (Van Pelt et al., 1999, Valkenburgh et al., 2007)**

Reservoir	**1994-98**	**2001-2**	**2003**	**2004**	**2005**	**2006**
Pig	24	25	26	23	24	21
Cattle	10	14	12	11	11	13
Chicken	19	15	11	13	14	14
Layers	37	35	37	37	32	36
Travel/other	9	11	13	15	19	16

The Danish approach is based on an intensive *Salmonella* surveillance programme in food animals and food products. A stochastic (Bayesian) model is used which also includes data on gross food consumption. Specific bacteria- and food source-related factors are introduced to account for e.g. differences in virulence between *Salmonella* serotypes and food characteristics.

In Denmark, pork and imported chicken, along with table-eggs, are important sources of human salmonellosis in Denmark. Imported and domestically produced beef, as well as domestically produced broiler meat, each account for a minor proportion of the human cases (Figure 2).

Source attribution using microbial subtyping has proved to be a valuable tool to inform risk managers in Denmark providing evidence for the need for initiating food safety initiatives as well as monitoring the effect of control programmes in place (Figure 2).

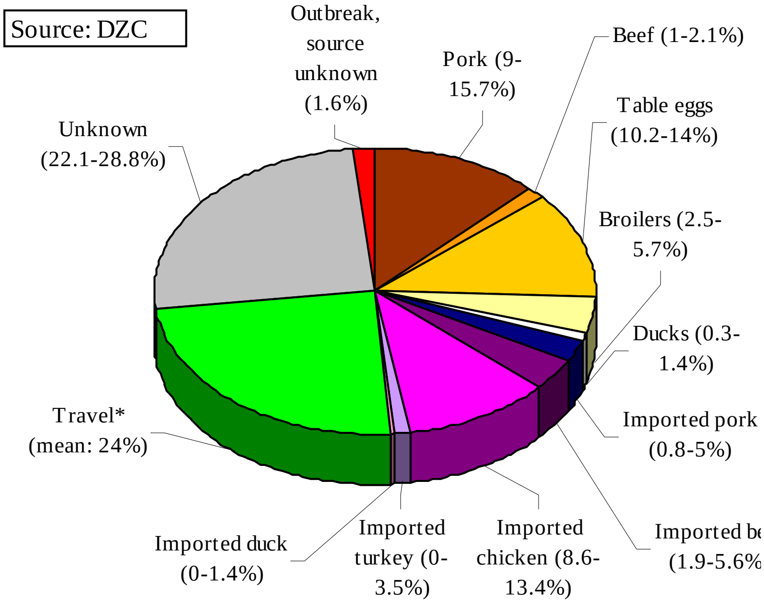


Figure 2: **Estimated major sources of human salmonellosis in Denmark in 2005 (Anon., 2006)**

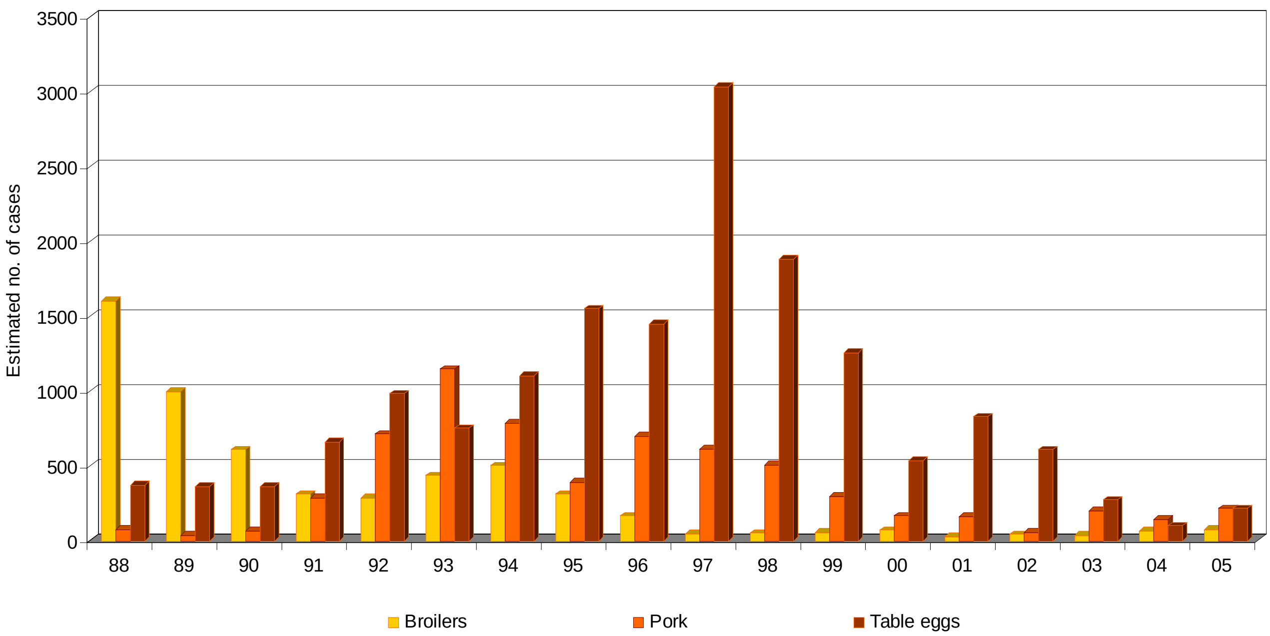


Figure 3: **Trends in the attribution of major sources of human salmonellosis in Denmark 1988-2005 (Anon. 2006)**

Figure 3 shows the human salmonellosis incidence associated with the three major sources of human salmonellosis in Denmark in the period from 1988 to 2005. The incidence of human salmonellosis was found to decrease in response to interventions in the broiler meat chain (1988), the pork meat chain (1993), and the egg chain (1997) (Wegener et. al 2003).

Factors related to the production and consumption of pork and poultry meat, as well as the *Salmonella* prevalence in animals, food and humans, may differ greatly between MS. As found in the EU-baseline study, the *Salmonella* broiler flock prevalence varies from e.g. 0 in Sweden, 1.6 in Denmark, 7.5 in the Netherlands, 15 in Germany up to e.g. 41.2 in Spain, 58.2 in Poland and 68.2 in Hungary. It is not known whether the attribution of pork and poultry to human salmonellosis in Denmark and The Netherlands is representative of the situation in other member states, but it is likely that both pork and poultry should be considered important sources for human salmonellosis throughout the EU, while beef is less important.

Application of microbial subtyping for source attribution of human salmonellosis requires integrated surveillance of the pathogen in most major (food) animals/ food and humans, providing a collection of representative isolates from reservoirs and humans, followed by the use of appropriate discriminatory typing methods (Hald *et al*., 2004). Data should, to the widest extent possible, reflect what the human population is exposed to. Active surveillance data is preferable to passively acquired data, and the use of results from veterinary diagnostic submissions should be avoided, as this data is not representative of the human population exposure.

The model assumes that prevalence data represents the reservoir level, meaning that the presence of the pathogen is tested as close as possible to the origin. In principle, data from the reservoir (farm) level should be given preference. In the Danish model, faeces data is used for poultry, whereas slaughterhouse data (swabs from the carcasses) is used for pork and beef. This is done because slaughterhouse data for pork and beef is assessed to be more representative of human exposure than farm data.

Microbial subtyping focuses on the reservoir level by attributing human cases directly to the source of exposure. As such, the method does not provide any information on the transmission route, meaning that the different pathways through which the pathogen can be transmitted to humans are not investigated.

The availability and representativeness of subtyping data from animal and/or food and human sources differ greatly between MS. This is reflected by the varying levels of detail of the official prevalence data that are being reported to EFSA and ECDC. However, more detailed data are available for some MS that were involved in national and international research projects. Currently, EFSA is carrying out baseline studies where MS collect data on the occurrence of specific foodborne pathogens in selected food animal production types according to a standardised protocol (e.g. *Salmonella* in layers, broilers and pigs). Results from these studies provide not only comparable prevalence estimates, but also a means for adjusting the official data reported by the MS. Unfortunately, the subtyping of isolates is not obligatory and performed on a voluntary basis. ECDC is receiving data of human foodborne illness from various existing networks such as the Basic Surveillance Network (BSN) and two dedicated surveillance networks (i.e. Enter-Net and Euro-TB). Unfortunately, subtyping data is not abundantly available at the discriminatory level that is required for human illness attribution modelling.

5.4 Source attribution by comparative risk assessment

The most recent development in attribution methods is the application of risk assessment methodologies, to quantify exposure to pathogens from a multitude of sources. Current methods estimate exposure per person per day, averaged over a specified population (e.g. all inhabitants of one country). Exposure is estimated separately for all relevant sources (food, animal contact, environment etc.).

Comparative exposure assessment has been applied to *Listeria monocytogenes* (FDA, USDA, 2003; FAO/WHO, 2004) and *Campylobacter* (Evers et al., 2008) but not yet to *Salmonella*, which typically occurs less frequently and in lower numbers in food products than *Campylobacter*, hence appropriate data may be more difficult to obtain.

The method requires many parallel exposure assessments to be made and is therefore resource intensive. It needs high-quality data for the occurrence of pathogens in all putative transmission routes and additional information on survival, contact frequencies, probability of ingestion of faeces given contact etc. As discussed above, such data are currently available to a limited extent, or the variables may be very difficult to measure in practice (latent variables), resulting in broad uncertainty intervals. However, some form of risk assessment is the only approach that in principle allows the high level of resolution required to answer the ToR2 requested by the Commission, e.g. for estimating the proportion of cases attributable to minced meat or other meat categories.

Given the current data limitations, it is concluded that comparative exposure assessment between major categories (food, animal contact, environment) needs further development and more data to be ready for decision support purposes. However, within each of these categories, comparative analysis of different food sources is feasible. The method can potentially integrate food chain information produced by national surveillance programmes or by special studies, and complements approaches that start with identified cases of human illness. Although data are available as presented in chapters 2 and 3 these data are not sufficiently robust for source attribution by comparative exposure assessment.

Depending on the questions to be answered, current data limitations could partly be overcome by agreement between risk assessors and risk managers on specific scenarios to be analysed. For example, calculations could be done for a range of prevalences and numbers of salmonellae in retail products, taking into account, for example, defined cooking and handling practices, and for specific consumption patterns. Uncertainty related to data limitations can also be explored by scenario analysis and may help to guide future data collection. Such approaches are also used in other domains of food safety risk assessment, e.g. for chemical substances.

Finally, it must be noted that exposure does not necessarily relate to illness in a linear way. Factors such as clustering of exposure, possible combined with immunity and illness-infection dose-response relationships must be taken into account when developing this method further.

5.5 Source attribution by expert opinion

A recent study in the USA has been published on the internet and in the peer-reviewed literature (Hoffman et al., 2006; 2007). In this study included 44 experts from different backgrounds (government, industry, academia) and different scientific disciplines (medicine, food science, public health, microbiology, and veterinary medicine. Expert estimates were compared with estimates based on outbreaks, as published earlier on the basis of CDC data. As expected, the degree of agreement between the two data sources varied per pathogen. There was close agreement for pathogens with dominant transmission routes (*Vibrio* spp. *Cyclospora cayatenensis*) but substantial disagreement for pathogens with multiple routes (*Campylobacter* spp., *Toxoplasma gondii* and *Cryptosporidium* spp.). Data for *Salmonella* spp. are shown in Table 7. The experts considered poultry to be the main source of salmonellosis, whereas outbreak data suggest eggs to be the dominant source. Pork appears to be a relatively small source of salmonellosis in the USA, based on outbreak data and in particular on expert estimates. These data cannot be directly transferred to the EU.

Table 7: **Food category attribution (% of cases) of salmonellosis in the USA, based on structured expert judgement and outbreak data (Hoffmann et al., 2006; 2007)**

Food category	Expert estimate	Outbreak data
Poultry[a]	35	18
Eggs	22	37
Produce[b]	12	17
Beef	11	6
Dairy	7	7
Pork	6	3
Seafood	2	-
Luncheon[c] and other meats	2	-
Beverages	2	-
Game	2	-
Breads and bakery	<1	-

- data not given but less than 5%
a poultry meat e.g. chicken, turkey
b fruit and vegetables
c cold sliced meats

In the Netherlands (Vargas-Galindo, 2007), 16 experts (from research and industry with backgrounds in microbiology, epidemiology and food science) provided their estimates on sources for 17 pathogens. There were two steps in the attribution. First, experts were asked to quantify the contribution of five major pathways, see Table 8 for results on human salmonellosis. Most cases were attributed to food but the mean estimate of 55% was lower than assumed in previous studies. Second, experts were asked to split the food pathway into 11 categories, see Table 9. Eggs, poultry meat, pork, beef and lamb were considered the most important sources, similar to the results of microbial subtyping.

Table 8: **Attribution (% of cases) to major pathways of human salmonellosis in the Netherlands, based on structured expert judgement (Vargas-Galindo, 2007)**

Food category	Expert estimate	Range 5 - 95 percentile
Food	55	32-88
Travel	14	3-26
Environment	13	0-29
Direct human-human transmission	9	0-19
Direct animal-human transmission	9	0-19

Table 9: **Food category attribution (% of cases) of salmonellosis in the Netherlands, based on structured expert judgement (Vargas-Galindo, 2007)**

Food category	Expert estimate	Range 5 - 95 percentile
Eggs and egg products	22	11-54
Chicken meat and other poultry meat	15	5-47
Pork	14	6-36
Beef and lamb	13	5-28
Dairy products	7	0-25
Fruit and vegetables	6	0-20
Other foods incl. composite foods	6	0-18
Infected humans and animals	6	0-18
Fish and shellfish	4	0-10
Bread, grains, pastas and bakery products	4	0-12
Beverages	<1	-

Expert judgements are subjective by nature and may be biased by the specific background and scientific expertise of the respondents. Methods exist to evaluate the expert's performance by evaluation of their answers to seed variables, i.e. variables to which the answer in known to the analyst but not generally available (Cooke, 1995). Experts are evaluated on their information and on their calibration. An expert is considered to provide informative results if the relative uncertainty in his estimates are small. An expert is well calibrated if the mean value of his estimate is close to the observed value for the seed variable. A structured procedure also helps to avoid many other pitfalls that may arise when asking experts for their subjective estimates. These structured approaches require more resources and technical expertise than conventional, unstructured evaluation and need a multidisciplinary approach. This may hamper their acceptance in practice.

Expert estimates typically combine information from different sources, which can be considered both a strength and a weakness. There are currently no analytical approaches for combining data from e.g. outbreak studies and epidemiological studies of sporadic cases, hence expert judgement is the only feasible way. The actual evaluation of the data and the weight put on any single data source is intractable, however. It has also been reported that experts base their judgements on traditional data and do not readily take new information into account.

Expert estimates have always played an important role in food attribution studies. Structured protocols and advance mathematical analysis are beginning to be applied and are potentially powerful tools to obtain consistent and complete estimates. Such studies, when carefully planned and executed, may provide policy-relevant information.

5.6 Overall conclusion from the source attribution methods

Based on information from the above five approaches to source attribution, eggs and egg products are the most frequently implicated sources in the EU, among the foodborne cases of human salmonellosis. Meat is also an important source of foodborne salmonellosis, with poultry and pork implicated more often than beef and lamb. More specific conclusions about the relative importance of specific meat categories brought into the kitchen raw, for example, fresh meat and products thereof, minced meat and meat preparations, cannot be made at the present.

For outbreak investigations, a major advantage is that these data are observed at the public health endpoint. A major limitation is however that the data may not reflect what occurs in sporadic cases. Microbial subtyping focuses on the reservoir level by attributing human cases directly to the primary source of exposure but the method does not provide any information on the transmission route. Case-control studies can be a valuable investigative tool, providing rapid results at low cost but due to the risk of introducing different study biases etc. (e.g. misclassification and recall bias) caution should be exercised unless results are confirmed by other, more robust evidence. Comparative exposure assessment has not yet been applied to *Salmonella*. The method requires many parallel exposure assessments to be made and is therefore resource intensive. However, comparative exposure assessment is the only approach that in principle allows the high level of resolution required to answer the ToR requested by the Commission, e.g. for estimating the proportion of cases attributable to minced meat or other meat categories. Expert estimates have always played an important role in food attribution studies. Structured protocols and advance mathematical analysis are beginning to be applied and are potentially powerful tools to obtain consistent and complete estimates. Such studies, when carefully planned and executed, may provide policy-relevant information. Because of the different strengths and weaknesses of the different methods for source attribution, and because they addresses different points in the food chain the method of choice in a given situation will depend on the specific questions and needs but comparing and compiling results from more than one method may provide more robust results than using only one approach.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. Different MS use different or multiple approaches for source attribution to human salmonellosis, e.g. outbreak data, analytical epidemiology of sporadic cases of salmonellosis, microbial subtyping, comparative risk assessment, and structured expert opinion.
2. Each method of source attribution has different strengths and weaknesses and addresses different points in the food chain. The choice of method is therefore dependent on the questions that need answering.
3. However, the available data are limited and sometimes not sufficient to make quantitative estimates of the contribution of meat to human salmonellosis across EU.
4. Even where data are available they are rarely fully used to identify the main sources of human salmonellosis in a source attribution model.
5. In the EU, among the foodborne cases of human salmonellosis, eggs and egg products are still the most frequently implicated sources. Meat is also an important source, with poultry and pork implicated more often than beef and lamb.
6. More specific conclusions about the relative importance of specific meat categories brought into the kitchen raw, for example, fresh meat and products thereof, minced meat and meat preparations, cannot be made at the present.

Conclusions from the specific approaches;

7. According to outbreak data in the EU, eggs and egg products are the foods most commonly implicated in human salmonellosis. Meat especially poultry and pork meats are also commonly involved.

8. Outbreak data collated at the EU level and in many MS do not allow clear identification of meat categories (such as carcasses, fresh meat and products thereof, minced meat and meat preparations) involved in human salmonellosis because foods have not been uniformly categorised. In addition, as information is rarely available on food handling and processing practices, it is rarely possible to trace back *Salmonella* contamination to the original source (food type) or to deduce the impact of consumer handling.

9. Case control studies of sporadic cases of salmonellosis have identified the same foods as for outbreaks, and several non-food related factors.

10. Source attribution through microbial subtyping in several MS (Denmark, Netherlands, Germany) has identified layers (eggs) as the major source of human salmonellosis. Among the meat producing animals, pigs and broilers are more important reservoirs for human salmonellosis than cattle. Such studies have not been published in other MS.

11. There are differences in serotype distribution in human cases in MS which may be a consequence of differences in serotype distribution and prevalence of *Salmonella* in food animals, differences in animal production, food processing, food preparation and hygiene and different food consumption patterns.

12. Comparative risk assessment allows the high resolution required to estimate the proportion of cases attributable to different meat categories as specified in the mandate.

13. Comparative risk assessment is highly dependent on the availability of adequate and relevant data, and this approach has not yet been used for human salmonellosis. In the absence of such data, initial analyses could be based on specific scenarios agreed between risk assessors and risk managers.

14. Where few, or contradictory, data are available, formal structured expert opinions can be an alternative option for estimating source attribution. The few formal structured expert opinions on *Salmonella* source attribution published identify eggs and poultry as the most important food sources. Other foods, including red meats, were also identified.

Conclusions on the applicability of the different approaches;

Because of the different strengths and weaknesses of the different methods for source attribution, and because they address different points in the food chain, the method of choice in a given situation will depend on the specific questions and needs. Comparing and compiling results from more than one method may provide more robust results than using only one approach.

RECOMMENDATIONS

- Case control studies are recommended as the most appropriate tool to quantify the proportion of sporadic human salmonellosis that is foodborne and to discriminate between specific food products within the same animal reservoir (e.g. bovine meat, milk and cheese) at the point of consumption.
- Within the foodborne category, analysis of appropriate microbial subtyping data and outbreak studies should be used to quantify the relative contribution of different meat animal species and other food types to human salmonellosis.
- Comparative risk assessment should be developed as the most appropriate tool to identify meat categories within the same reservoir that pose a greater risk to individual consumers or the population as a whole.
- Data gathering for purposes of attribution should be question driven and by representative sampling. Baseline studies, as carried out under the Zoonoses regulations, are an important development.
- In the short term, a structured expert survey might provide the EC with an initial set of estimates for attribution of foodborne human salmonellosis to different meats and products thereof. Due to differences in food production and consumption, such a study would ideally need to be performed in each MS and then aggregated to the EU level.
- Community guidelines for analytical and descriptive epidemiological studies of foodborne illness would be helpful and improve comparability of results.

Data requirements for use of microbial subtyping for source attribution;

- It is recommended that all *Salmonella* isolates from cases of human illness and a representative set of isolates from all main animal species entering the food chain is serotyped in all MS and that at least the common serotypes such as *S*. Enteritidis and *S*. Typhimurium are subtyped using harmonised and appropriate methods.
- Isolates from the EU-baseline studies should be typed as suggested above, or at least conserved for future typing.
- When available, such data should be analysed using appropriate statistical models for the purpose of reservoir attribution.

Data requirements for use of comparative risk assessments for source attribution;

- Data on the prevalence and number of *Salmonella* in retail products must be available for products to be compared in specific scenarios agreed upon by both risk assessors and risk managers.
- In the absence of such data, initial analyses should be based on specific scenarios agreed between risk assessors and risk managers.
- In addition, data on food storage, handling, preparation and consumption that reflect the diversity of consumer habits in the EU should be available.

Data requirements for use of outbreak data for source attribution

- It is recommended to develop a minimum dataset including standardised food categories and reporting of contributing factors linked to outbreaks, to be collected in each MS and reported to EFSA.

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