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Special Review

Salmonellosis – a cause of concern and a challenge

H.-J. Sinell

Institut für Lebensmittelhygiene, Freie Universität Berlin

Salmonellose – Grund zur Betroffenheit und Herausforderung

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Worldwide zoonosis

The Nutrition Report („Ernährungsbericht") of the Federal Government recorded 91,237 cases of salmonellosis in 1990. This is more than double the number registered in 1980. Compared to 1970, the figure has increased by the factor 7.6. Intensified investigations in connection with the Salmonella Surveillance Program of the Federal Government might have resulted in an increase of reported incidents before 1980. The situation then appeared to stabilize, the number of cases even dropping for a few years. However, hopes of having attained a plateau or possibly of having the problem under control were disappointed. The rapid spread of the infection during the late 1980s and, above all, the unparalleled record of 1990 exceeded the worst expectations. The system of sampling and investigation as well as interpretation of the data has not changed for many years. Consequently, the recent dramatic increase in the frequency of salmonellosis is certainly not a result of intensified investigations.

As far as recording systems exist, the increase of salmonellosis is a world-wide phenomenon. Reports from WHO at the beginning of the 1980s, have shown the incidence of salmonellosis in Third World countries to vary from a figure comparable to Germany (Kenya, Mexico, Turkey) to 30 times (Senegal) or nearly 100 times that figure (Guinea-Bissau, Angola). The rise in salmonellosis is therefore not a specific German or European problem. We are just approaching the international level.

Taxonomy and pathogenicity

To enable a better understanding of what should be done, some details will be recalled. Salmonellae are gram-negative, and usually (with one exception) motile rod-shaped bacteria that belong to the family Enterobacteriaceae. *S. choleraesuis* and *S. enterica* are regarded as species of their own, the latter one including seven subspecies and 2200 immunologically distinct serovars. Salmonellae cause disease that can be naturally transmitted between vertebrates and also to humans. A very few serovars are more or less host-adapted, but the vast majority is transmitted between many host species. True host specificity exists solely with regard to S. typhi infection in humans. Salmonellosis is the classical zoonosis.

Infection occurs usually via the oral route. An incubation period of 12 to 36 (rarely, 5 to 72) h and an unspecific prodromal stage are followed by abdominal pain, fever (usually $\leqq$ 38 °C) and diarrhea. In view of the short incubation period and of the clinical picture similar to poisoning, the disease is often termed a toxi-infection or toxico-infection. The acute stage of illness is overcome in most cases after 8 to 14 days. There are also severe progressive forms that are complicated by cardiovascular disorders requiring intensive care. *S. choleraesuis* infection – fortunately rarely found – may often assume a septic course and end fatally. The overall lethality is about 0.1 % and involves, in particular, the newborn and the elderly.

A minimum number of cells (i.e., the minimum infective dose) must be ingested in order to cause overt illness. It was believed for many years that about 10^5 living Salmonella cells must be ingested to cause disease in man. However, several more recent reports have shown that as few as 3 to 10 cells/g may lead to manifest infection. Accordingly, every finding of salmonellae in a sample of ready-to-eat food – irrespective of their actual number – must be regarded at least as a potential health hazard. To introduce tolerance levels or sampling schemes with acceptance numbers ("c")[1)] would indeed be a disastrous mistake.

Knowledge about the mechanisms of virulence has been considerably extended during the past decade. Chromosomal determinants and plasmids have been detected that encode adhesion and invasion in the host cell. Fimbriae, adherence factors and hemagglutinins have also been identified. Certain polypeptides that are synthesized in the bacterial cell enhance adhesion to the intestinal mucosa, lipopolysaccharides hamper phagocytosis of macrophages, and iron-chelating siderophores compete with the host cell for bio-available iron. Hydrophobic proteins of the bacterial cell surface, so-called porines, are said to interfere with transmembrane diffusion and to inhibit phagocytosis of polymorphonuclear leucocytes and macrophages. Their action has still not been elucidated. It has not yet been established whether the mechanisms of virulence of salmonellae are controlled by the same principle in all serovars.

Enterotoxin has been detected in a number of serovars. The toxin activates adenylate cyclase in the cytoplasm membrane, thereby inducing formation of 3′,5′-cyclo-AMP and excretion of fluid. This correlates well with the mode of action of LT produced by ETEC and the mode of action of the cholera toxin. Salmonella enterotoxin is immunologically closely related to both of the latter.

Spread, chains of infection, epidemiology

The organism persists outside the host and may multiply if temperature and environmental conditions are adequate. International trade with contaminated feedstuffs has contributed to the spread of the infection in livestock and in pets. Manifold chains of infection link feeds, animals, foods, humans, sewage and waste materials. Besides livestock and pets, "animal" includes also game and other wild animals, rodents and insects. The animal keeps a central position within the chain of infection and maintains the cycles of infection. The situation is complicated by asymptomatic (human or animal) carriers who periodically or continuously excrete salmonellae. Those clinically healthy individuals pose a steady hazard to the health of other humans or animals.

The biology of salmonellae plays a significant role in the spread of the organism. As salmonellae multiply in a moist environment at temperatures above 6 °C, surface water, sewage, feeds of animal origin, or bedding materials can become sources of contamination. Contaminated foods and excretors contribute to the dissemination of the organisms. Living vectors may transmit salmonellae to food: animal pests such as rodents and insects, and wild birds such as pigeons and gulls. Various items may act as vehicles, such as transport vessels, containers, working surfaces, e.g., tables, cutting boards, and tools such as knives, saws, choppers, wiping cloths(!), grinders, cutters, slicers, and humans themselves, either with their clothes or with their bare (or even glove-protected) hands. Staff health and hygiene is accordingly an important factor in the epidemiology of salmonellosis. It should be mentioned, however, that it may be the contaminated food itself that could contaminate or even infect the food handler.

Salmonellosis has become a world-wide problem for several reasons. International trade with foodstuffs and feeds of any kind is nearly barrierless and facilitates the spread of the organism. Large-scale raising of livestock is common in the developed world and is also increasing at a tremendous rate in some developing countries. Feedstuff concentrates (particularly when based upon fish-meal and bone-meal that are produced in tropical areas), usually contain salmonellae. Industrialized animal husbandry produces huge amounts of frequently contaminated slurry, liquid manure, and waste water. This is also true for slaughterhouses that release large volumes of contaminated sewage. Handling practices in abattoirs inevitably entail cross-contamination of carcasses of healthy animals. Particular salmonella hazards arise from the mass production of poultry. This is reflected in the dramatic increase of poultry- and egg-associated salmonellosis outbreaks recorded in most European countries during the past 5 years.

The epidemiological characteristics of salmonellosis have markedly changed within this period. *Salmonella typhimurium* had been the prevailing serovar listed in records worldwide until particular phage types of *S. enteritidis* began to emerge in the mid-1980s. According to the records of the Division of Enteric Pathogens of the Public Health Laboratory, London, this serovar already accounted for the vast majority of the Salmonella isolations in 1988. The reasons for this phenomenon require elucidation. It appears to be quite certain that the organisms have not changed their virulence patterns when compared with the strains that had been isolated many years before.

Foods as a vehicle carrying the infective agent

As the living animal may suffer from salmonellosis or excrete the bacteria, it is primarily the food of animal origin that initially carries the organisms. Moreover, foods of plant origin may become cross-contaminated in various ways. 3589

[1] c = the maximum allowable number of defective sample units or marginally acceptable sample units. When more than this number are found in the sample, the lot is rejected.

strains that had been isolated from foods associated with salmonella outbreaks in the Federal Republic of Germany in 1982 originated from the following sources: 18.8 % minced meat (raw), 18.6 % delicatessen salads (including potato salad), 9.1 % ice cream, 6.9 % poultry. The most spectacular salmonella epidemic comprising 16 284 cases, many of which ended fatally, occurred in the vicinity of Chicago in Spring 1985. Technical defects in the pipeline system of a dairy plant had caused contamination of skimmed liquid milk with *S. typhimurium*.

Recent reports from several countries of the EEC stress poultry, poultry products and, above all, eggs and dishes containing egg as a primary cause of infection. It has been well established and clearly identified as a hazard in the present situation of poultry production, something that had been considered doubtful for a long time: the transovarian transmission (infection/contamination) of salmonellae into the developing egg. The rate of eggs contaminated in such a way and offered for sale is reported to vary between 0.01 and 0.1 % (or even higher).

Tenacity and hazards through mishandling

Environmental conditions in the food that limit the growth of microorganisms are important factors to be considered in the drafting of concepts for preventive measures. Salmonellae do not multiply in foods with a pH ≤ 4.5 or $a_w \leq 0.95$. Also, temperatures ≤ 6 °C inhibit growth of Salmonella. Heating to internal temperatures of ≥ 70 °C for ≥ 10 min kills the most heat-resistant Salmonella strains. Certain environmental factors such as low water activity or high fat content considerably increase the heat resistance of the organism.

Many foodstuffs can be expected to have a very low contamination with salmonellae, e.g., poultry or pig offal. Particular health hazards, however, arise when the microbes get a chance to multiply. This is usually the case with temperature abuse. Minced pork, for instance, that is often eaten raw in Germany, may frequently contain salmonellae. When minced pork has been on a "cold" buffet, of course at room temperature, a density of the bacteria will be attained within 3 or 4 h which is certainly sufficient to cause infection. Similar mishandling occurs during periods of keeping dishes warm in the critical temperature range between 10 and 60 °C, particularly when the products have been insufficiently heated beforehand: grilled meats, "rare" roast beef, flamed dishes, soups, sauces, reconstituted instant baby foods.

Finally, the hazards resulting from recontamination and cross-contamination must be stressed. Recontamination may have disastrous effects in products that have been heat-processed. Since a competitive flora is absent in these products, salmonellae may find optimal growth conditions. Drip fluid from offal or from thawing poultry must be mentioned as a particular hazard in the home. Another important source of contamination is dust that is sucked from fan openings from outside and spread afterwards within the production area, for instance, in plants producing dried milk or egg products.

Prevention and control

Measures of prevention and control must be applied to three levels:
- Animal production

- Food production and processing
- Education.

Due to the steady increase of salmonellosis, control is highly important, also in terms of health policy. The Federal Health Council "Bundesgesundheitsrat" as an advisory body for the Federal Government of Germany has commented on salmonellosis in two resolutions and has published recommendations on control that will be reviewed briefly in the following.

Animal production

A number of preventive measures could be effectively implemented at the beginning of the food chain ("first line of defense"):
- Decontamination of feedstuffs.
- Development of vaccines and large-scale immunization programs, first, in poultry production and followed by corresponding measures in pig and cattle production.
- Stepwise establishment of salmonella-free grandparent and parent herds.
- Provision or improvement of conditions of salmonella-free animal housing. Improved methods for removal/disinfection of sewage sludge, manure, waste.
- Improvement of animal transport and slaughtering hygiene. Slaughterhouses should be salmonella-free premises. Improvement of byproduct processing. Intensification of insect, rodent, and pest control at all steps of animal production. Prevention of access of other animals (dogs, cats, birds) to premises where animals are slaughtered or are being kept before slaughter.

Food production and processing

Measures referring to the control of food production and processing ("second line of defense") can be summarized as:
- Prevention of contamination (e.g., by cleaning and disinfection, hygiene of personnel);
- Reduction of contamination (e.g., through proper processing);
- Prevention of growth of microorganisms (maintenance of the cool chain).

Generally, strict separation of "clean" and "unclean" areas has high priority. One must carefully check the hygienic conditions of food operating areas, equipment, tools and surfaces that may come into contact with foods. Consistent application of the HACCP system is indispensable. This concept is based upon analysis of the microbiological hazards (in this case Salmonella) peculiar to the product and the processes applied in a particular factory. Hazard analysis is followed by the identification of the critical control points (CCPs). A CCP is a location, practice, procedure or process at which control can be exercised over one or more factors which, if controlled, could minimize or prevent a hazard (ICMSF, 1988). Appropriate criteria must be chosen that indicate whether the operation is under control. These criteria must be monitored in the most effective way. Pasteurization of milk is a convincing example for a CCP. Recording of time/temperature data monitors the process. In countries with stringently restricted sale of raw milk (e.g., Scotland), the incidence of samonellosis due to consumption of milk from infected cows is approximately zero. HACCP has proven to be much more effective in preventing salmonellosis than any type of random sampling and investigation of end products.

Education

Everybody who has to handle or otherwise process food must obtain a minimum level of knowledge on the causes and significance of salmonellosis (and other foodborne infections and intoxications). Education and training programs must focus on various groups of people:
- Manufacturers and producers, particularly those who produce, prepare or process foods of animal origin;
- Staff who are directly responsible for processing, preparation, and distribution of ready-to-eat foods;
- Staff who are responsible for storage and transportation of foods;
- The public and the ultimate consumer;
- Official food control authorities;
- Persons who have to develop and implement quality assurance programs, e.g., in the sense of HACCP.

Appropriate information and education must take into account the level of understanding and the responsibility allotted to the particular group of people in the food chain. Programs must encompass:
- Origin and spread of the organisms within the working area of the person who is responsible for particular operations;
- Routes, vehicles and vectors transmitting the organism;
- The impact of extrinsic, intrinsic and process factors, especially time/temperature conditions that affect growth, survival or death of microorganisms. Significance of CCPs.
- Practices of personal cleanliness. Improvement of knowledge in hygiene, development and training of appropriate behavioral patterns in individuals who handle or can directly or indirectly contaminate food. At the level of the ultimate consumer ("third line of defense"), sharpened awareness of the hazards involved in handling food in the home would be extremely helpful as a preventive measure.

Conclusions

There is need for improvement of knowledge in various areas:
- Improvement of husbandry practices to minimize risk of infection at the farm level;
- Rapid identification of animal (and human) carriers. Rapid detection of salmonellae in feeds and development of cheap and effective methods to decontaminate those feeds;
- Development and improvement of vaccines effective in protecting against salmonellosis or preventing the carrier state in food animals;
- Development of useful epidemiological markers and further clarification of mechanisms of virulence;
- Improvement of decontamination procedures to reduce the surface contamination during and following slaughtering;
- Development of slaughtering techniques that will effectively prevent the contamination of carcasses and the environment with intestinal contents;
- Transfer the HACCP approach to slaughterhouses and establishments processing animal products.

More important than conducting those research programs is to take immediate action on the basis of the first and second "defense line" described above. Taking individual measures separately will waste time and money. The only possible way of improving the situation is concerted action that utilizes all the measures specified. This would indeed require funds that will hardly be available as the Treasury is empty, particularly for the time being. Yet the public must consider and decide where to place public health priorities. Control of salmonellosis is a political decision.

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Authors's address:

Prof. Dr. H.-J. Sinell, Institut für Lebensmittelhygiene, Freie Universität Berlin, Königin-Luise-Str. 47, 1000 Berlin 33