Strategies to control *Salmonella* and *Campylobacter* in raw poultry products

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Summary

Foodborne illness is a major public health concern. The largest number of foodborne illness cases attributed to poultry and poultry products are caused by paratyphoid serotypes of *Salmonella* and by *Campylobacter jejuni*. The effective prevention of foodborne disease requires an understanding that contamination can be introduced into foods at numerous points along the food chain.

Since multiple entry points exist for foodborne pathogens, multifaceted intervention approaches are required to successfully control contamination of poultry during the various phases of the growth period and processing procedure of broiler chickens. Strategies during the grow-out period (the period during which day-old chicks are raised to six- to seven-week-old broiler chickens) include sanitation, biosecurity, vaccine and drug therapy, and biological control procedures, such as those aimed at preventing colonisation. There are also many critical control points identified in the processing plant which reduce contamination. These include temperature controls (washer and product), chemical interventions, water replacements and counter-flow technology in the scalders and chillers, and equipment maintenance. Transportation and food handling at retail outlets and by the consumer (i.e., storage at the proper temperature and adequate cooking) are the final critical control points in the farm-to-table continuum.

It is important to apply risk reduction strategies throughout the food chain. These include: easing the development and implementation of voluntary animal production 'best management practices', implementing in-plant hazard analysis and critical control point systems, developing effective transportation and refrigeration standards, working to facilitate adoption of the model *Food Code* in all States and providing educational materials and support for public health activities nationwide.

Keywords

*Campylobacter* - Foodborne illness - Poultry - Public health - Risk reduction - *Salmonella* - United States of America.

Introduction

Morbidity and mortality in humans

While precise data on the incidence of illness associated with microbiological contamination of meat and poultry is limited, foodborne illness is an important public health problem in most countries. Data from the Centers for Disease Control and Prevention (CDC) suggest that foodborne microbial pathogens account for up to seven million cases of foodborne illness each year, and up to 7,000 deaths in the United States of America (USA) (76).

The 'Healthy People 2000' review ranks foodborne diseases as a priority. Food safety priorities for 2000 include the control of *Salmonella*, *Campylobacter*, *Escherichia coli* O157:H7 and *Listeria monocytogenes* (77).

Clinical manifestations in humans

Diarrhoea is one of the most common symptoms associated with significant human morbidity and mortality. Diarrhoea
incurs medical costs, economic costs for businesses and personal costs due to lost labour/employment for individuals and their families. It is important to note that children are most severely affected by diarrhoea; the leading cause of death in children is diarrhoea. In developing countries, three million children die of diarrhoea each year and countless millions more suffer pain, malnutrition and growth retardation from diarrhoea. Diarrhoea may be caused by viruses, bacteria, protozoa, parasites and chemicals. Among the most common bacterial causes of human diarrhoea are Salmonella, Shigella, Yersinia and Campylobacter. Studies have been conducted which show that Campylobacter is a much more common bacterial cause of diarrhoea than Salmonella, Shigella or Yersinia.

Salmonella
Salmonella bacteria associated with poultry or poultry products usually cause an intestinal infection in humans – accompanied by diarrhoea, fever and abdominal cramps – which often lasts for a week or more. Salmonella bacteria are spread from reservoirs in the animal world to humans, most frequently through foods of animal origin, such as eggs, meat and poultry.

Approximately 2% of affected persons later develop recurring joint pains and arthritis. People of all ages are affected, and the incidence is highest in infants. In the very young, the elderly, or in people whose immune systems are deficient, infection can spread to the bloodstream, the bone marrow or the meningeal linings of the brain, leading to severe and occasionally fatal illness.

Campylobacter jejuni
Campylobacter jejuni is a more common source than Salmonella of bacterial gastroenteritis causing diarrhoea. Campylobacteriosis is demonstrated clinically in two different ways:

a) the disease begins as a flu-like syndrome with muscle aches, fever, abdominal pain and malaise followed by a watery, explosive diarrhoea with abdominal cramping
b) the disease causes a watery, explosive diarrhoea with abdominal cramping

Bloody diarrhoea may be seen in both cases.

The incubation period after infection and before symptoms appear is usually three to five days, and may be as long as ten days. After recovery, the patient may continue to excrete C. jejuni for two to five weeks and for as long as several months. A case-control study by Kapperud et al. showed the occurrence of symptoms in patients with campylobacteriosis (Table I).

Complications of infection by C. jejuni may include abdominal pain resulting in appendectomy (without appendicitis), reactive arthritis, Reiter’s syndrome or Guillain-Barré syndrome. Research shows that 38%-46% of patients with Guillain-Barré syndrome had an antecedent infection with C. jejuni. The colon is sometimes involved and this disease pattern is called enterocolitis. Recovery from this form of infection is very slow, and involvement of the colon may result in a mistaken presumptive diagnosis of Crohn’s disease or chronic ulcerative colitis.

Sources of human infection/epidemiology
Salmonella
In the USA, nearly five million cases of illness and more than 4,000 deaths may be associated with meat and poultry products each year. An estimated two million cases (with approximately 1,000 deaths) are attributable to Salmonella spp. In 1999, a total of 41,222 confirmed cases of salmonellosis were reported to the CDC by State and local health departments. The most commonly incriminated foods in outbreaks of salmonellosis in humans are those of animal origin, such as meat, milk and eggs. In the USA, most of these outbreaks occur in the summer months, when more opportunity for food handling abuse exists. Fruit juices, fruits (such as melons) and other uncooked foods have also been incriminated in foodborne outbreaks.

For foodborne disease cases linked to poultry, Salmonella and Campylobacter create the highest risk in comparison to other agents. Three serotypes account for more than 50% of all human isolates of Salmonella. The same three serotypes, S. Typhimurium, S. Enteritidis and S. Heidelberg, account for approximately 40% of all non-human isolates. S. Enteritidis and S. Heidelberg are the serotypes most frequently isolated in poultry surveillance and diagnostic samples submitted to the National Veterinary Services Laboratory of the United States Department of Agriculture (USDA). In a survey of Salmonella in broilers conducted between 1990 and 1992, the three most frequently isolated serotypes were S. Hadar, S. Heidelberg and S. Kentucky.
communication). In most developed countries, poultry meat is frequently contaminated with *Salmonella* and *Campylobacter* spp., the organisms responsible for many cases of human enteritis (46).

Two major factors affecting the number and severity of *Salmonella* infections include the dose (number of organisms) consumed by an individual and the number of individuals exposed to the *Salmonella* organism (21). The number and severity of *Salmonella* infections vary with food preparation and consumption patterns. Low doses in prepared (and undercooked) foods are amplified if the foods are held at room temperature. The handling of raw carcasses or fluids which may be associated with the raw poultry carcass can be a source of cross-contamination of other foods which are not to be cooked. The risk of illness may be further amplified in commercial or institutional food service settings where larger quantities of food are being prepared at one time.

**Campylobacter jejuni**

In the USA, species identification has been made of 91% of the *Campylobacter* isolates submitted to the CDC; of these, 99% have been identified as *C. jejuni*, which is the most common cause of campylobacteriosis, and humans most commonly become infected with *C. jejuni* from meals which include the preparation of raw poultry (71).

The epidemiology of campylobacteriosis reveals two distinct patterns. One pattern involves an outbreak in which a large number of people develop clinical symptoms. A second pattern is that of a sporadic or single isolated case. The majority of cases of campylobacteriosis are sporadic cases. The disease is transmitted through the consumption of undercooked poultry or through the cross-contamination of other foods by contaminated knives, kitchen utensils or cutting surfaces. Table II shows the essential difference between sporadic cases of campylobacteriosis and those cases which are part of an outbreak of the disease (71).

**Table II**

Patterns of campylobacteriosis in the United States of America

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Campylobacteriosis</th>
<th>Sporadic cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>Water or milk</td>
<td>Poultry</td>
</tr>
<tr>
<td>Season</td>
<td>Spring and autumn</td>
<td>Summer</td>
</tr>
<tr>
<td>Case fatality rate</td>
<td>≤ 3/10,000</td>
<td>Unknown</td>
</tr>
</tbody>
</table>

The reported isolation rate of *C. jejuni* in the USA is five isolates per 100,000 population. However, this rate appears to underestimate the true incidence of campylobacteriosis because many laboratories do not routinely culture for *C. jejuni*, and many States in the USA do not require reporting of isolates.

A better estimate of the incidence of campylobacteriosis in the USA is based on several studies. In a study of eight hospitals, *Campylobacter* species were isolated twice as frequently as *Salmonella* and 4.5 times as frequently as *Shigella* as a cause of diarrhea. This means that *Campylobacter* infection rates would be 36-40/100,000 population (8). At a health maintenance organisation in Seattle, USA, the rate of campylobacteriosis was 70/100,000 population in 1982 (37) and 50/100,000 in 1985 (44). Under-reporting of cases of campylobacteriosis may also be due to physicians who do not order a culture for patients with diarrhea. It is estimated that cultures are requested for two-thirds of patients with diarrhea. Based on this estimate, the true rate of *Campylobacter* enteritis is probably 54-60/100,000. In addition, there is under-reporting of cases of campylobacteriosis by patients who do not consult a physician: these are less severe cases of campylobacteriosis. Based on figures from one outbreak, it has been estimated that there are eighteen mild cases of campylobacteriosis for every case examined by a physician (56). Thus the incidence of *Campylobacter* enteritis may be 960-1,080/100,000 population (71).

The number of *Campylobacter* enteritis cases which occur each year in the USA would be estimated at 2.1 to 2.4 million cases or 1% of the total population. The mortality rate in the USA resulting from gastroenteritis caused by *C. jejuni* or subsequent complications is unknown because the infection is not reported as a cause of death on death certificates (the ICD-9 or International Classification of Disease – Ninth Revision, does not specify *Campylobacter* infections). If the death rate (3 deaths/10,000 infected) found in one outbreak of *C. jejuni* was applied to sporadic cases, an estimate of the number of deaths per year due to sporadic *C. jejuni* infection would be 680 to 730 in the USA (71). However, this estimate probably exceeds the true rate, since the deaths in this one outbreak were of elderly persons or persons with compromised immune systems, whereas sporadic cases usually occur in younger individuals in good health.

Other countries have reported isolation rates of *C. jejuni* as follows:

- Christchurch, New Zealand: 179/100,000 (10)
- New Zealand: 86/100,000 (10)
- Freiburg, Germany: 20/100,000 (38)
- Ontario, Canada: 290/100,000 (74) (probably related to raw milk)
- United Kingdom: 58/100,000 (64).

The frequency of specific bacterial enteritis (percentage isolated from diarrhoeal specimens) attributed to known enteropathogens isolated from cases of gastroenteritis in North America and Europe is shown in Table III (67). This clearly demonstrates that *C. jejuni* is more commonly isolated from cases of gastroenteritis than either *Salmonella* or *Shigella* (20, 30).
Description of the agents

Salmonella

Salmonellae are part of a family of Gram-negative, rod-shaped bacteria known as Enterobacteriaceae, which occur in the intestinal tract of humans and in warm-blooded and cold-blooded animals. To date, more that 2,300 serotypes of Salmonella are known to exist and new serotypes are being discovered each year. Of these recognised serotypes, only about 100 are routinely isolated from food, animals and man (16). Enterobacteriaceae are different from some of the other Gram-negative organisms in that, as facultative cells, these bacteria are able to survive and thrive in a wide variety of environmental conditions and on a wide variety of nutritional substrates. This ability to survive extremes of environmental conditions, combined with the wide host range, makes control very difficult (42).

Campylobacter jejuni

Campylobacter is a Gram-negative, microaerophilic, slender, curved motile bacterium. Due to slow growth and microaerophilic requirements, standard culture methods require selective media. Campylobacter jejuni has been found in the stools of infected people, wildlife and pets, as well as most farm animals (including cattle, swine and poultry) irrespective of whether they are sick or healthy.

Presence of bacteria in live poultry

Colonisation of Salmonella in poultry

Probably the greatest single factor which limited the early expansion of the poultry industry in the USA was the disease known as bacillary white diarrhoea, caused by Salmonella Pullorum. A species-specific egg transmitted Salmonella of poultry, S. Pullorum was rampant in poultry and could cause over 80% mortality in chicks. The poultry industry developed the National Poultry Improvement Plan (NPIP) as a voluntary co-operative State-Federal programme in 1934 to produce breeding chickens certified free of S. Pullorum and S. Gallinarum. The NPIP allowed for a co-ordinated effort to test birds for pullorum disease and to eliminate the reactors from breeding flocks. This programme has been very effective in the elimination of S. Pullorum from these breeding flocks. With the rapid elimination of pullorum disease from the commercial poultry industry, a dramatic increase in size of the commercial poultry industry, a dramatic increase in size of these flocks and numbers of breeding chickens was possible (52). At present, programmes under the NPIP include control of egg-transmitted Salmonella (i.e., S. Pullorum, S. Gallinarum, S. Enteritidis) and Mycoplasma (i.e., Mycoplasma gallisepticum, M. synoviae and M. meleagridis).

Table III

Frequency of pathogen as a percentage of all species of bacteria isolated from diarrhoeal specimens by country

<table>
<thead>
<tr>
<th>Enteropathogen</th>
<th>Country</th>
<th>Canada*</th>
<th>Canada*</th>
<th>England</th>
<th>Scotland</th>
<th>Sweden</th>
<th>USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Campylobacter</td>
<td></td>
<td>2.1</td>
<td>4.3</td>
<td>13.9</td>
<td>8.7</td>
<td>10.9</td>
<td>4.6</td>
</tr>
<tr>
<td>Salmonella</td>
<td></td>
<td>1.8</td>
<td>5.1</td>
<td>4.3</td>
<td>2.5</td>
<td>7.2</td>
<td>2.3</td>
</tr>
<tr>
<td>Shigella</td>
<td></td>
<td>1.1</td>
<td>1.4</td>
<td>3.8</td>
<td>6.7</td>
<td>3.5</td>
<td>1.4</td>
</tr>
<tr>
<td>Yersinia</td>
<td>enterocolitica</td>
<td>0.1</td>
<td>0.6</td>
<td>-</td>
<td>-</td>
<td>0.7</td>
<td>-</td>
</tr>
</tbody>
</table>

* Two studies were conducted in Canada

Many case-control studies of campylobacteriosis have identified the most common cause of both outbreaks and sporadic cases of campylobacteriosis as raw broiler chicken used in the preparation of meals. The biological plausibility of raw broiler chicken being the vehicle of transmission of C. jejuni is well established for sporadic cases of campylobacteriosis.

A case-control study performed at the University of Georgia, USA, identified three risk factors for campylobacteriosis, as follows:

- eating fully cooked broiler chicken (odds ratio [OR] = 4.7)
- eating broiler chicken reported to be raw or undercooked (OR = 9.0)
- contact with a cat or kitten (OR = 9.0)

There was no duplication between the serotypes of C. jejuni in the humans and those found in the cats, and the cats were not considered a source of C. jejuni for the humans (14).

A case-control study in south-eastern Norway found poultry consumption to be associated with campylobacteriosis. Illness was more often associated with the purchase of (presumably unfrozen) raw broiler chicken in Sweden or Denmark on weekend trips, and was not associated with the purchase of frozen broiler chicken in Norway (32).

In King County, Washington State, USA, a case-control study showed that consumption of broiler chicken and Cornish game hen was responsible for more than doubling the risk of C. jejuni enteritis (19).

The infectious dose of C. jejuni at which diarrhoea develops is as low as 500 cells, although some individuals will not develop diarrhoea at a dose of one million cells of C. jejuni. There is not a clear infectious dose (ID₅₀) at which 50% of patients will develop diarrhoea (6). This means that efforts to reduce morbidity and mortality due to campylobacteriosis should be directed towards reducing the amount of C. jejuni on each broiler chicken carcass, at least to a level of 1,000 to 10,000 C. jejuni cells per carcass.
The clinical signs of infection with other serotypes of Salmonella may be evident in young birds, but infected adult breeders often exhibit little or no morbidity and fertility is usually not significantly reduced. In contrast to the pathogenic relationship between Salmonella and humans, Salmonella generally have a commensal relationship with chickens. Poultry carry most serovars with slight or no symptoms and the infection can remain undetected in flocks. Birds exposed to Salmonella shed the organism, resulting in contamination of the environment and of other birds. Subsequent contamination of the transport vehicles at the time of harvest may contribute to the contamination of the carcass or meat product during slaughter and processing.

Many factors affect the susceptibility of chickens to Salmonella colonisation. These include:

1. the age of the chicken
2. the survival ability of the pathogen through gastric acidity
3. the effective competition of Salmonella with other bacteria
4. the ability of the pathogen to locate a hospitable colonisation site
5. the nature of the diet fed to the chicken
6. the physiological status of the chicken
7. the health and disease status of the chicken
8. environment stresses
9. medication effects
10. the host genetic background

Unless there is disease or temperature stress, the highest level of intestinal colonisation of Salmonella in broilers generally occurs during the second or third week of grow-out (the period during which day-old chicks are raised to six- to seven-week-old broiler chickens), after which there is a gradual decline in frequency which continues until the time of processing.

Poultry become infected with Salmonella in three main ways: by direct contact with clinically ill or symptomless birds, by the consumption of contaminated feed or water and through the environment. The hatchery may be the most important source of Salmonella in broilers and this is an important point in the prevention of colonisation or significant reduction of Salmonella from chickens during production. At hatching, most chicks have very few microflora in the gut and are far less susceptible than older chicks to Salmonella colonisation. Canadian research suggests that a bird on day 7 will require a challenge 10,000 times greater than a day-old chick to become infected with a pathogen such as Salmonella.

Although Salmonella contamination of eggs is low, 5% to 9% of day-old chicks in commercial hatcheries give positive results when tested for Salmonella (29). The higher frequency of recovery of salmonellae from chicks, as opposed to hatching eggs, may indicate that the hatchery is a major source of contamination (4). In 1992, Bailey et al. demonstrated that a single Salmonella-contaminated egg could substantially contaminate all eggs and newly hatched chicks within a hatching cabinet during the hatching process (4).

The second major opportunity for contamination arises during the grow-out period. Feed, rodents, birds, insects, untreated water and litter are all potential sources of Salmonella contamination. Salmonella-colonised chicks delivered to the grow-out house provide a ready source of salmonellae for colonisation of other chicks in the flock (7). The grow-out house is a building in which chicks are placed and grown until they are six to seven weeks of age, at which time the chicks are transported to slaughter.

Stress of transportation amplifies Salmonella levels present during the grow-out period. Sampling in broilers has indicated a Salmonella level between 5% and 10% near the end of the grow-out phase. In one study, faecal dropping samples collected in broiler houses about one week prior to slaughter were contaminated at a rate of 5.2%, while Salmonella was found in 33% of the samples collected from live haul trucks at the processing plants (29).

**Colonisation of Campylobacter jejuni in broiler chickens**

Campylobacter spp. are not pathogenic for broiler chickens. When broiler chickens are first colonised with C. jejuni, mild diarrhoea would probably be the only manifestation of colonisation, and in some cases there would be no sign at all. Campylobacter is not considered an animal husbandry problem for the broiler chicken industry in terms of animal health. For this reason, no effort is made to prevent colonisation of broiler chickens by C. jejuni as part of a flock health maintenance plan.

Properly processed egg products are an extremely unlikely source of C. jejuni contamination (22). C. jejuni has been recovered from shell membranes, but not from the albumen or yolk. Transmission of C. jejuni to broiler chickens through the egg is highly improbable (48). In a study of vertical transmission of C. jejuni from breeder flocks to broiler chicken eggs, 74% of birds tested in breeder flocks showed cloacal carriage of C. jejuni. Eggs from breeder flocks were examined for C. jejuni penetration, and 185/187 were free of Campylobacter. These findings do not support a role for vertical transmission of C. jejuni in commercial broiler chicken production (61).

Campylobacter jejuni is not present in the droppings of newly hatched chicks, but colonisation arises within days after exposure to C. jejuni. Once C. jejuni appears in a flock, the pathogen spreads rapidly to virtually all the chickens (62).
The percentage of chickens still colonised has been shown to decrease from 72% to 100% of the flock at seven weeks of age to 20% to 46% of the flock at forty-two weeks of age. However, there are broiler chicken flocks which are raised free of Campylobacter (40).

Broiler chicks are not born with C. jejuni in the intestinal tract but become colonised through the environment. Once a few of the broiler chicks become colonised, the entire flock will be colonised within a few days.

The ecological niche of C. jejuni has been well described by Altenruse et al. (1). Campylobacter jejuni is found in water, animals and food. C. jejuni is found among feral as well as domestic animals, and in birds, mammals and insects. The wide distribution of C. jejuni among animals necessitates a level of biosecurity within and around the grow-out house which excludes domestic as well as feral birds and mammals (1). House flies have been shown to be carriers of C. jejuni (55, 60), thus, grow-out houses need to be constructed to exclude flies as well as domestic and feral mammals and birds from the broiler chicken environment.

Stern et al. conducted a study which examined the influence of transportation of broiler chickens from the grow-out house to the slaughter plant on the number of Campylobacter spp. recovered from the carcass of the broiler chicken. The results of the study show that the transportation and holding of broiler chickens in coops prior to slaughter and processing of the carcass contribute an additional load of Campylobacter spp. of > $10^{4}$ colony-forming units (CFU)/carcass to the number of Campylobacter spp. normally found on processed broiler chicken carcasses (70). These results are summarised in Table IV. In an associated field study, Campylobacter spp. contamination of the broiler chicken carcasses increased on the surfaces (i.e. feathers) of birds during holding and transport of the broiler chickens to the processing plant. In the subsequent process of defeathering the broiler chicken carcasses, the Campylobacter spp. contamination of the feathers spreads to the skin surface of all broiler chicken carcasses, regardless of the initial Campylobacter spp. load which each individual broiler chicken may have had in the intestinal tract or on the feathers.

Of note in this study was one farm on which the broiler chickens were free of Campylobacter spp. The carcasses and caeca remained free of Campylobacter spp. even after transport. These results indicate that broiler chickens can be brought to processing facilities without becoming infected with Campylobacter (70). Stern reports that differences were not readily apparent between the practices on this farm and the other nine farms on which broiler chickens were colonised by C. jejuni.

**Prevalence of Salmonella during processing**

Poultry arrive at the slaughter processing plant with various amounts of faecal contamination on the skin and feathers. Evisceration may contribute to the contamination of carcasses, although generally the viscera are removed in such a way that contact of intestinal contents with the carcass is prevented. Data indicate that crops are far more likely (86-fold) than caeca to rupture during processing, which increases the possibility of carcass contamination with Salmonella derived from crop contents. These studies suggest that the crop may serve as a source of carcass contamination with Salmonella within some processing plants (17).

In one survey, 21.4% of all processed broiler carcasses sampled at processing plants gave positive results for Salmonella. Salmonella was found about half as frequently in birds exiting the chiller as in birds at later packaging points; this suggests that plant workers or equipment cross-contaminated carcasses. Salmonella Typhimurium was the serotype most commonly isolated from processed broiler carcasses (29).

The USDA/Food Safety and Inspection Service (FSIS) microbiological baseline data collection programmes focused on establishing a microbiological baseline for broiler chickens. Salmonella was recovered from 20% of the broiler carcasses analysed. Over 95% of these positive carcasses yielded three or fewer Salmonella per cm² of broiler surface area as enumerated from positive carcass rinse fluids (75). The actual numbers of Salmonella organisms on broiler carcasses leaving the processing plant are usually very low. These carcasses are not considered to be a serious health risk if prepared using ordinary cooling and cooking practices. However, if not properly cooked, held, cooled and stored, the pathogens present could cause foodborne illness.

There has been concern that processing innovations may be responsible for increased incidence of human enteric disease as a result of inspections at faster line speeds. A study conducted by the FSIS did not find a correlation between increased line speeds and bacterial contamination of broilers while the process operated under demonstrated control.

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**Table IV**

**Effect of transportation on the Campylobacter count in caeca and on the carcass of broiler chickens after slaughter**

<table>
<thead>
<tr>
<th>Source</th>
<th>Location of slaughter</th>
<th>Grow-out house (before transportation) (mean count)</th>
<th>Research laboratory (after transportation) (mean count)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caeca</td>
<td></td>
<td>$10^{6.44}$</td>
<td>$10^{6.15}$</td>
</tr>
<tr>
<td>Carcass</td>
<td>CFU of Campylobacter spp./g carceral matter</td>
<td>$10^{4.65}$</td>
<td>$10^{7.11}$</td>
</tr>
<tr>
<td>Carcass</td>
<td>CFU of Campylobacter spp./carcass</td>
<td>$10^{6.95}$</td>
<td>$10^{6.11}$</td>
</tr>
</tbody>
</table>

a) not significantly increased
b) significantly increased

CFU: colony-forming units
Mean bacterial counts and *Salmonella* prevalence did not change significantly with processing line speeds. Carcasses were cleaner at each successive site in the process at all line speeds for aerobic plate count (APC), Enterobacteriaceae and *E. coli*. None of the trials demonstrated a significant change in the proportion of carcasses with *Salmonella* at successive sites for any line speed (9).

**Campylobacter jejuni counts in broiler chickens and broiler chicken products**

Despite a reduction in the percentage of carcasses showing the presence of *C. jejuni* during processing, products at the end of processing are still found to be contaminated with *C. jejuni*. There is a trend towards an increasing percentage of samples being contaminated with *C. jejuni* during the week from Monday to Wednesday, and the percentage of samples contaminated with *C. jejuni* also increases throughout the day on any day of the week. Rates of positivity are highest from July through to October. July is the month with the highest rates of *Campylobacter* contamination. These findings support the previously reported epidemiological data showing that sporadic cases are associated with broiler chickens and with summer time. As in the processing plant, the percentage of retail broiler chicken products which gave positive results for *C. jejuni* increased during the week. The reduction in prevalence of *C. jejuni* contamination in retail products (24%) compared to finished products at the processing plant (62%) has been attributed to the sensitivity of *C. jejuni* to the temperature ranges and oxygen to which the finished product may be exposed during the five days between slaughter and retail purchase of the broiler chicken (18).

A two-year study to determine the effect of season and refrigeration on the contamination of broiler carcasses by *C. jejuni* found that contamination was heaviest in the winter, summer, and autumn, and that *C. jejuni* could not be detected after 10 days of refrigerated storage at 4°C. Table V summarises the study results (66). This study also confirms the findings that the lowest levels of *C. jejuni* colonisation in the intestinal tract of broiler chickens occur during the spring (23). In addition, a study by Kinde et al. demonstrates that *C. jejuni* counts are diminished after refrigeration (36).

### Table V

<table>
<thead>
<tr>
<th>Season</th>
<th>Recovery technique (% positive)</th>
<th>Mean counts per carcass</th>
<th>Control strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Direct plating</td>
<td>Enrichment recoveries</td>
<td>Before refrigeration</td>
</tr>
<tr>
<td>Winter</td>
<td>95</td>
<td>95</td>
<td>16,000</td>
</tr>
<tr>
<td>Spring</td>
<td>20</td>
<td>50</td>
<td>4</td>
</tr>
<tr>
<td>Summer</td>
<td>90</td>
<td>100</td>
<td>3,100</td>
</tr>
<tr>
<td>Autumn</td>
<td>45</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
| ? not detectable

**Salmonella**

Breeder flock management requires aggressive biosecurity programmes and sanitation standards. Testing and monitoring of breeders for *Salmonella* should include guidelines such as those in the National Poultry Improvement Plan (NPIP). At the biennial conference of the NPIP held in June 1996, several changes in the NPIP provisions were approved, including the establishment of a "US Salmonella Monitored" programme for primary meat-type chicken breeding flocks (52).

**Hatchery programmes**

Hatchery programmes are important. The Agricultural Research Service (ARS) of the USDA conducted a five-year study which showed a decline of 63% in the prevalence of *Salmonella* contamination in three commercial broiler hatcheries from 1990 to 1995 (57). Three possible reasons exist for the reduction in salmonellae contamination, as follows:

- the use of more effective sanitising chemicals
- the use of clean breeder nest materials
- the institution of better sanitation practices industry-wide.

Good egg and hatchery sanitation can reduce *Salmonella* infection in broiler chicks.

During the last five years, significant advances have been made in the development of various production practices.
aimed at producing salmonellae-free birds (57). In the hatchery, these include the following:

a) Effective washing and sanitising of hatching eggs at the breeder farm. A wide variety of bacteria can be prevented through the chemical treatment of eggs as soon as possible after laying; this method may also increase egg production and may reduce the number of newly hatched chicks contaminated with *Salmonella*. Polyhexamethylene biguanide hydrochloride, hydrogen peroxide and a phenolic compound have been identified as the most effective chemicals to eliminate *Salmonella* from fertile hatching eggs (13).

b) Disinfecting the air in hatching cabinets. Bacterial cross-contamination is a problem in the hatchery environment: however, a good sanitation programme can significantly reduce *Salmonella* in the hatchery. Sanitised circulating air in the hatching cabinet is effective in reducing the spread of *Salmonella*. Sanitising treatments such as ultra violet light, hydrogen peroxide and ozone are effective in reducing Enterobacteriaceae and *Salmonella* in hatching cabinet air samples (4).

c) Administering a yeast-type preparation to the hatching chicks. Yeasts such as *Saccharomyces cerevisiae* var. *Boulardii* have a component of the cell wall structure to which *Salmonella* attach in preference to the gut wall. The yeast and attached salmonellae are then purged from the intestines by physiological defence mechanisms (41).

d) Administering a competitive exclusion product. This allows for long-term protection against gut colonisation by *Salmonella* when given to chicks both in the hatching cabinet and in the first drinking water in the grow-out house. Colonisation, especially at a very young age, by beneficial micro-organisms such as lactobacillus and streptococcus helps to protect the chicks against motile *Salmonella* and pathogenic strains of *Escherichia coli*. Native (desirable) populations can competitively exclude unwanted micro-organisms such as *Salmonella*. A number of different competitive exclusion products are currently being marketed and tested in poultry culture (3, 12).

**Feed and water sources**

Under some circumstances, feed can be a source of *Salmonella*. In September 1990, the Food and Drug Administration (FDA) Center for Veterinary Medicine (CVM) announced a goal of zero *Salmonella* contamination in animal feed ingredients and finished feed. In 1993 the FDA conducted a survey of processors manufacturing either animal or vegetable protein products used in animal feeds. The data indicated that *Salmonella* occurs in both animal and vegetable protein samples (43). However, through monitoring the serotypes found in feed ingredients and processed poultry, Brunton was able to report that the *Salmonella* serotypes found in feed ingredients were not the same as those normally found in processed poultry 95% of the time (47).

Mashed feed should not contain animal protein or should include only animal protein products produced under the Animal Protein Producers Industry Salmonella Reduction Education Program (15). The use of pelleted feed is recommended since the pelleting process generates heat which can kill *Salmonella*. Dedicated feed delivery vehicles and good sanitation practices (as well as biosecurity/rodent control) help prevent poultry feed from being contaminated.

Periodic, routine testing of the water source for toxic chemical residues and bacteria is important. Chlorination of the water supply helps to prevent water-borne spread of micro-organisms.

**Litter management**

Litter management may be an important management tool in the control of *Salmonella* during the grow-out period. Water activity, which is the level of unbound water, affects the levels of *Salmonella* growth since the organism is able to grow only at water activities above 0.94. The reduction of water activity to below a level of 0.80 will result in negative or minimal *Salmonella* survival. Water activity, levels of *Salmonella* in the litter and the degree of carcass contamination all appear to be linked (45, 50).

Proper litter management also contributes to the control of insects and rodents which are known to carry and amplify bacterial pathogens. Rodent control (by rodent-proofing facilities, rodent trapping and baiting) is a critical control point in all phases of production, from the brooding facility to the hatchery and in the grow-out facility, as well as at the feed mill.

**Biosecurity – rodent and pest control programmes**

Biosecurity involves using all measures possible to control the spread of disease-causing organisms. An all-in-all-out programme followed by a rigorous cleaning and disinfection programme is recommended. Rodent control, especially while the premises are empty, is very important to prevent recontamination of the environment by *Salmonella*-infected rodents after cleaning and disinfection. The restricted movement of birds, people and equipment, combined with good sanitation, helps to control the spread of disease-causing micro-organisms, and possibly zoonotic pathogens. An important element in disease prevention is to avoid contact between poultry and migratory water fowl and to ensure that small birds cannot again access to the poultry house.

As biosecurity on farms is reinforced, the importance of factors such as ‘catching crews’ must be addressed. Vehicles, cages and crates used for broiler movement can also transmit diseases from farm to farm and can be an important source of *Salmonella* contamination (53). Better designed crates and improved ways to sanitise transport crates are critical needs for the industry.
Pre slaughter preparation – feed withdrawal programmes

Preparation for transportation to the slaughter establishment commences days before the birds are shipped to the plant. Management of the birds during the days and hours prior to processing determines the amount of reprocessing which may be required.

There appears to be some value in the withdrawal of feed prior to slaughter but this issue is more complicated than originally thought. Feed withdrawal times vary according to eating patterns. The emptying process of the crop occurs gradually in the 90- to 120-minute period after the bird has eaten. Birds must have access to water during the withdrawal period; if the bird does not drink, dry feed will remain in the crop indefinitely. Another potential problem is an increase in pH within the gastrointestinal tract during feed withdrawal, which promotes Salmonella growth. In addition, the intestinal strength starts to decrease after 12 to 14 hours off feed. The intestines become more easily broken after 18 hours off feed. Furthermore, in the absence of complex proteins, the caeca appear to become more friable and thus more susceptible to rupture during the evisceration process. To obtain full benefit from withdrawal, glycans may need to be added to the water used during the withdrawal period (59).

Campylobacter jejuni

Effective reduction of C. jejuni populations on poultry carcasses begins on the farm to which Campylobacter-free broiler chicks are introduced. These Campylobacter-free broiler chicks can become infected and colonised with C. jejuni through their environment. The most effective measures to minimise or prevent the initial colonisation of broiler chicks by C. jejuni will be taken on the farm and in the grow-out house; examples of these measures are given below.

Disinfection of water systems

Broiler chicks and broiler chickens should be provided with clean, chlorinated water through a water distribution system which has nipple drinkers (to avoid faecal contamination). Water was shown to be the predominant source of C. jejuni on a broiler chicken farm in southern England where an outbreak of campylobacteriosis in humans occurred in 1984. The presence of the serotype of C. jejuni remained in the human population served by the broiler chicken farm until the serotype was eradicated from the farm in 1986. C. jejuni was found at all levels of the bore-hole as well as in the sediment at the bottom of the well from which water was obtained for the grow-out house. Examination of pipes of the water distribution system revealed a biofilm. Culture of the biofilm failed to grow any Campylobacter. However, immuno-fluorescent testing demonstrated clumps of vibrioid Campylobacter cells. This line of evidence gives strength to the argument that a few of the broiler chicks became colonised with ‘viable but non-culturable’ C. jejuni which leaked from the biofilm into the free-flowing water. Once these few broiler chicks became colonised, there was rapid horizontal transmission to the rest of the flock. The concept of ‘viable but non-culturable’ C. jejuni was advanced by Rollins and Colwell (54). Transmission of ‘viable but non-culturable’ C. jejuni to Campylobacter-free broiler chicks has been demonstrated by Stern et al. (69). An intervention programme of chlorination of the water supply, cleaning and disinfection of the drinking system of the grow-out house and withdrawal of furazolidine from feed reduced the proportion of broiler chickens colonised with C. jejuni from 81% to 7% and reduced the C. jejuni recovered from broiler chicken carcasses by a factor of 1,000 to 10,000. Two months after the chlorination intervention was terminated, the broiler chicken flocks returned to an 80% colonisation rate, which suggests that there was temporal association between chlorination of the water supply and reduction in the colonisation rates of the broiler chickens with C. jejuni (51).

Standard operating procedures

Sanitation standard operating procedures (SOPs) should be followed in the grow-out houses. Failure to maintain sanitation SOPs has long been recognised as a potential cause of colonisation of broiler chickens with C. jejuni. This failure has been characterised by the following actions:

- easy access to the grow-out house and immediate surroundings by other farm animals (pigs, goats, free-range broiler chickens, dogs and cats), by feral animals (rats, mice and other rodents) and by households
- failure by farmers to restrict access of other farm workers to the grow-out house
- failure of those farm workers with valid access to the grow-out house to change boots and use a chlorine footbath prior to entering the grow-out house (i.e. maintenance of a disinfection barrier) (2).

Rodent and pest control programmes

Having an effective rodent and pest control programme is an important contamination reduction measure. Grow-out houses should be constructed in such a manner as to exclude rodents, wild animals, pets, domestic animals, and personnel not directly needed in the care of the broiler flock. The effectiveness of vector control has been demonstrated in multiple studies.

Specific effective interventions are listed below:

- cleaning and disinfection of the broiler chicken house between successive broiler chicken flocks
- hygienic precautions of separate clothes and boots for personnel available at the entrance of the broiler chicken house
- a footbath disinfection barrier
- hand-washing facilities
- concrete floors in the broiler chicken house for a level floor
- a concrete apron around the broiler chicken house with a fence and gate at the periphery of the concrete apron
- chemical and physical control of rodents
- control of insect populations (79).

Kapperud et al. concluded that to reduce the prevalence of Campylobacter in broiler chicken flocks, 'preventive measures should include disinfection of drinking water and strict hygienic routines when farm workers enter the rearing room' (Table VI). Furthermore, disinfection of drinking water is the preventive measure most likely to have the greatest impact on the prevalence of Campylobacter among broiler chicken flocks in the study area (33).

Table VI
Risk factors independently associated with an increased risk of colonisation of broiler chicken flocks with Campylobacter jejuni

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Odds ratio</th>
<th>P value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeding broiler chickens non-disinfected water</td>
<td>3.42</td>
<td>0.045</td>
</tr>
<tr>
<td>Tending other poultry prior to entering the grow-out house</td>
<td>6.43</td>
<td>0.007</td>
</tr>
<tr>
<td>Tending pigs prior to entering the grow-out house</td>
<td>4.98</td>
<td>0.037</td>
</tr>
<tr>
<td>Geographic region (Hedmark vs Ostfold County)</td>
<td>2.91</td>
<td>0.023</td>
</tr>
<tr>
<td>Season (autumn vs other seasons)</td>
<td>3.43</td>
<td>0.008</td>
</tr>
<tr>
<td>Presence of rats on the farm</td>
<td>3.96</td>
<td>0.383</td>
</tr>
</tbody>
</table>

* Probability that the finding or outcome occurred by chance alone

Other studies have also shown that hygienic conditions are very important for the production of Campylobacter-free broiler chickens, or for minimising the number of strains found within the grow-out house (34, 63). Such production controls have been demonstrated to be effective and are relatively inexpensive.

More sophisticated techniques for reducing the colonisation of broiler chickens with C. jejuni are under investigation. These techniques include development of broiler chickens which are resistant to colonisation by C. jejuni (68), immunisation with an oral vaccine against the flagellum of C. jejuni (35), competitive exclusion (58, 65) and addition to the feed of a yeast to which C. jejuni adheres, thereby preventing colonisation (J. Line & N.J. Stern, personal communication). Transportation of broiler chickens to processing plants managed with a technique which prevents droppings of broiler chickens in upper-level coops from falling onto broiler chickens in the coops below would help prevent cross-contamination of skin and feathers during transport to the processing plant.

Pathogen reduction during processing
Regular schedules of cleaning and disinfection of the slaughter/processing plant and equipment are essential for maintaining sanitary conditions. Plants must now have sanitation SOPs. Personnel must also practice good personal hygiene and must wear special protective outer clothing in many locations.

Feather removal begins with scalding, or submersion in hot water with an overflow of 960 ml/carcass, followed by mechanical picking. External contaminants are removed during scalding, picking and rinsing, but these processes also serve to distribute bacteria. Results of a study conducted by the FSIS demonstrated that there was a reduction in the proportion of carcasses contaminated with salmonellae when a countercurrent scalding with a post-scalding carcass rinse was used (Table VII). The proportion of carcasses containing Salmonellae decreased significantly at pre-evisceration, pre-chill and post-chill sites. The proportion of carcasses contaminated with Salmonellae in this study was higher at the post-chill site than at the pre-chill site (49% compared to 28%). This no doubt was caused by cross-contamination in the chiller. These percentages indicated that although simple scald changes contributed substantially to the improvement of the bacterial quality of chicken carcasses, additional interventions in the chilling process (such as chlorination of chill water) are important to control cross-contamination and to preserve the positive effects obtained by the scald changes (25, 27).

Carcass chilling, if carried out properly, should effectively control microbial growth on carcasses. The FSIS determined the populations of bacteria on poultry during processing at a slaughter plant in Puerto Rico in 1987. Results indicated that slaughter, dressing and chilling practices significantly decreased the bacterial contamination on poultry carcasses, as determined by counts of aerobic bacteria, Enterobacteriaceae and Escherichia coli (26).

However, carcass chilling carries the risk of cross-contamination because large numbers of carcasses are present at any one time in the same tank of water. Even though contaminated carcasses are rinsed, some residual contamination may remain and may spread from bird to bird during chilling. Immersion chilling dilutes the contaminants on any single bird but also serves to spread bacteria to previously uncontaminated carcasses. The USDA, FSIS conducted a study to determine the effect of adding chlorine to carcass and giblet chill water on bacterial contents of raw poultry products (Table VIII). Placing raw chicken carcasses in chlorinated chill water reduced aerobic, Enterobacteriaceae and E. coli plate counts. Results indicate that chlorination of chill water aids in the control of bacterial cross-contamination of carcasses, giblets and necks (24).

The National Broiler Council (NBC) and the United States Poultry and Egg Association conducted a study in 1991 on microbial reduction through the implementation of the following methods:
- counter-flow scalding
- post-scald hot water carcass sprays
### Table VII
Results of bacteriological culturing of carcass rinses before and after changes in scalding techniques (26)

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of carcasses tested</th>
<th>APC (a)</th>
<th>Enterobacteriaceae (a)</th>
<th>Escherichia coli (a)</th>
<th>Salmonellae prevalence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline (before scalding changes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-evisceration</td>
<td>160</td>
<td>4.05</td>
<td>3.07</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>Pre-chill</td>
<td>160</td>
<td>3.39</td>
<td>2.28</td>
<td>1.46</td>
<td></td>
</tr>
<tr>
<td>Post-chill</td>
<td>158</td>
<td>3.14</td>
<td>2.32</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td><strong>Scalder changes</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-evisceration</td>
<td>99</td>
<td>3.73 (b)</td>
<td>2.70 (a)</td>
<td>2.08</td>
<td></td>
</tr>
<tr>
<td>Pre-chill</td>
<td>99</td>
<td>3.18 (b)</td>
<td>2.25</td>
<td>1.81</td>
<td></td>
</tr>
<tr>
<td>Post-chill</td>
<td>49</td>
<td>2.97 (b)</td>
<td>1.56 (a)</td>
<td>0.89</td>
<td></td>
</tr>
</tbody>
</table>

APC: aerobic plate count
(a) mean log$_{10}$ colony-forming units per carcass for aerobic plate count
(b) significant ($P < 0.01$) decrease from the corresponding number in the baseline study

- addition of 20 ppm total chlorine to the bird wash in the picking room, the water used on the transfer belt and the final wash
- addition of chlorine in the chill water at a level to allow for 1 to 5 ppm free chlorine in the overflow from the chill tank.

The study resulted in a significant reduction in the bacterial load on carcasses (80). The NBC has recommended that all Council members voluntarily adopt the proven interventions.

Occasionally, viscera are ruptured and contents spill on the edible product. Intestinal rupture may occur if evisceration equipment is not properly adjusted and monitored. More adaptable machines (which adjust for size variation) are being developed, which may improve this aspect of processing. A robotic system to accomplish removal of meat from non-eviscerated chicken carcasses is also under development. By removing meat prior to evisceration, possible contamination from spilled contents of the body cavity can be reduced or eliminated (81).

Chemical spraying methods have been investigated in an attempt to reduce bacterial and faecal contamination on poultry carcasses during processing. At present, the poultry industry uses mainly water spray, or water with chlorine, or chemical dipping during processing, to reduce bacterial contamination. The USDA has approved an edible grade of trisodium phosphate for use as a dip or rinse for poultry to reduce bacterial load.

Bacteriocins should be useful as biopreservatives to prevent the growth of foodborne pathogens and food spoilage bacteria in ready-to-eat poultry and other food products (28). Bacteriocins are peptides or protein antimicrobial substances produced by bacteria which have potential use as antimicrobial agents in foods. Further study is necessary before these agents will be approved for use during poultry processing.

Low-voltage electricity has been studied as a method to destroy bacteria in saline water, poultry processing water, chicken skin or chicken drumsticks. Results have shown that pulsed low-voltage electricity with a low concentration salt solution reduced S. Typhimurium and C. jejuni on chicken skin by more than 1 log (90%), and the treatment eliminated S. Typhimurium, C. jejuni and aerobic bacteria in poultry chilling water (39).

### Table VIII
Results of bacteriological culture of carcass rinses before and after chlorination of chiller water

<table>
<thead>
<tr>
<th>Location</th>
<th>No. of carcasses tested</th>
<th>APC (a)</th>
<th>Enterobacteriaceae (a)</th>
<th>Escherichia coli (a)</th>
<th>Salmonellae prevalence (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline (no chlorination of chiller water)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-evisceration</td>
<td>160</td>
<td>4.06</td>
<td>3.07</td>
<td>2.17</td>
<td></td>
</tr>
<tr>
<td>Pre-chill</td>
<td>160</td>
<td>3.39 (b)</td>
<td>2.29 (a)</td>
<td>1.46 (b)</td>
<td></td>
</tr>
<tr>
<td>Post-chill</td>
<td>158</td>
<td>3.14 (b)</td>
<td>2.32</td>
<td>0.87 (b)</td>
<td></td>
</tr>
<tr>
<td><strong>Chlorination of carcass chiller</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-evisceration</td>
<td>99</td>
<td>3.99</td>
<td>3.22</td>
<td>2.72</td>
<td></td>
</tr>
<tr>
<td>Pre-chill</td>
<td>50</td>
<td>3.20 (b)</td>
<td>2.57 (b)</td>
<td>2.04 (b)</td>
<td></td>
</tr>
<tr>
<td>Post-chill</td>
<td>50</td>
<td>2.51 (b)</td>
<td>1.75 (b)</td>
<td>1.20 (b)</td>
<td></td>
</tr>
</tbody>
</table>

APC: aerobic plate count
(a) mean log$_{10}$ colony-forming units per carcass
(b) significant ($P < 0.01$) decrease from the previous number in the column
(c) significant increase from the previous number in the column
In the future, meat irradiation, used in conjunction with proper food processing and preparation techniques, could further reduce contamination of slaughtered poultry. Radiation doses sufficient to kill pathogenic bacteria do not induce significant changes in the character or quality of the meat (72). The USDA approved the use of irradiation for poultry in the autumn of 1992.

**Food handling**

In the farm-to-table continuum, post-processing food handling is very important in the reduction of foodborne illnesses caused by *Salmonella* and *Campylobacter*. Foodborne diseases usually arise when the causative organism, initially present in low numbers, is allowed to multiply on the chicken carcass surface during production, distribution, preparation or storage of foods. Since *Salmonella* multiply very slowly at 10°C, and not at all at 6°C to 7°C, growth on carcasses should be entirely prevented by prompt and efficient chilling (46). Inadequate cooking also can result in foodborne illness. Proper cooking should destroy the micro-organisms present on the chicken carcass. *Salmonella* is sensitive to heat and, generally speaking, the organisms are killed at temperatures of 70°C or above (16). *Campylobacter* bacteria are extremely fragile and are easily destroyed by thorough cooking. Usually the bacteria are present only on the surface of the chicken carcass, which facilitates the effectiveness of proper cooking temperatures. Cross-contamination of foods which are not to be cooked contribute to the problems arising from unsafe food handling.

The FDA is providing the model *Food Code* for adoption by those jurisdictions which have regulatory responsibility for food service, retail and vending operations (78). The model *Food Code* updates the food safety laws of the USA and addresses interventions and strategies needed to prevent problems during retail and food handling. The *Code* also places greater emphasis on the health, knowledge and responsibilities of industry management and personnel, and highlights the importance of time/temperature controls and safe food-handling practices. Even more importantly, the new *Code* incorporates a framework for the application of hazard analysis and critical control point (HACCP) principles at retail outlets (78).

**Future research needs**

The agenda for change in food safety is to establish a farm-to-table strategy with risk reduction strategies as key components all along this continuum. As reductions in pathogen contamination in meat and poultry plants occur through improvements in process control, food safety concerns which arise outside the plants must also be addressed. Those involved in the production, transportation and retail sale of meat and poultry products, as well as food handlers, must share food safety responsibility.

Numerous intervention strategies are currently available in poultry production. The key now is to identify which of these strategies are reasonable, economically feasible and effective at the production level. This is a high priority for all areas of food animal agriculture. More research is needed to identify food safety control points which can be incorporated by industry into ‘best management practices’.

While the determination of which best management practices result in a reduction of pathogens in the live animal is important, there is also a real need to determine whether changes in animal production practices translate to actual decreased public health risks for the consumer. It is not sufficient to reduce pathogens; there must also be a clear, visible link to improved public health.

Questions must be asked as to whether any of the recommended interventions have any effect on the incidence rate of foodborne illness in the human population. The incidence levels of gastroenteritis due to *C. jejuni* are unknown in most countries. Norway has been tracking the incidence of *campylobacteriosis* and results have shown a rise in the incidence rate over time. However, most industrialised nations have collected data on gastroenteritis due only to *Salmonella*, *Shigella* and *Yersinia*. For this reason, clinical laboratories have in turn directed efforts toward the isolation and identification of *Salmonella*, *Shigella* and *Yersinia*. Clinical laboratories in general are not equipped to isolate and identify *C. jejuni* due to technical challenges and costs for such detection.

An active surveillance programme with sentinel sites has been established in the USA, and the results from this surveillance programme will be available in the near future. The data from these sentinel sites will be needed for the following reasons:

- a) to determine whether *C. jejuni* is the most common bacterial cause of gastroenteritis
- b) to make a national (USA) annual estimate of campylobacteriosis and to evaluate the annual economic cost of the disease
- c) to establish the need for including *C. jejuni* with *Salmonella* in the surveillance of bacterial gastroenteritis
- d) to encourage clinical laboratories to begin routine culture for and identification of *C. jejuni*.

With the regular inclusion of *C. jejuni* in the surveillance programme for bacterial gastroenteritis, a national incidence rate of campylobacteriosis will be determined. The effect of interventions may then be inferred by changes in the national incidence rate of campylobacteriosis.

An important factor to consider is that incentives for the farmer at the broiler chicken grow-out houses to institute the recommended interventions do not exist at present. *Campylobacter jejuni* and generally *Salmonella* are not
pathogens which affect broiler chickens; there is no loss/mortality in the poultry population due to colonisation; there may not be a reduction in weight or feed conversion due to colonisation; there is no demand on the part of the processing plant (to whom the farmer sells poultry colonised with \textit{Salmonella} and \textit{C. jejuni}) for poultry with reduced colonisation. The processor does not currently pay a premium for poultry with reduced \textit{Salmonella} or \textit{C. jejuni} counts.

As HACCP principles are implemented in the slaughter establishments, however, plants will be considering the potential hazards associated with incoming poultry. The identification of animal production practices which are reasonable and which assure plants of the safety of animals supplied for slaughter will be an important element. The FSIS is establishing pathogen reduction performance standards for \textit{Salmonella} which will require all slaughter establishments to reduce the prevalence of \textit{Salmonella} contamination of finished meat and poultry carcasses to below the national baseline prevalence (as established by the most recent FSIS national microbiological baseline data) (75). Therefore, careful examination of the impact of production and pre-slaughter practice interventions which might reduce the level and the frequency of carcass contamination will be essential. Additionally, data needs to be collected to establish how these changes relate to the occurrence of foodborne illness. Data collected which permit sound risk assessments from farm-to-table will enable experts to determine the feasibility and effectiveness of food safety interventions. On-going research and epidemiological studies of poultry, slaughter plants, processing, distribution, retail and human population active surveillance data is providing the framework to accomplish this goal.

Stratégies de lutte contre \textit{Salmonella} et \textit{Campylobacter} dans les produits avicoles crus

P.L. White, A.R. Baker & W.O. James

Résumé
Les toxi-infections alimentaires constituent un grave problème de santé publique. Parmi ces maladies, le plupart de celles qui sont associées à la consommation de viande de volaille et de produits avicoles sont dues aux sérotypes paratyphoïdes de \textit{Salmonella} et à \textit{Campylobacter jejuni}.

Pour une prévention efficace des toxi-infections alimentaires, il faut savoir que la contamination des aliments peut survenir en de nombreux points de la chaîne alimentaire.

Comme les agents pathogènes transmis par les aliments peuvent avoir plusieurs points d’entrée, il convient de mener une action à plusieurs niveaux au cours des différentes phases de la croissance des poulets de chair et de leur transformation, afin de lutter efficacement contre la contamination des volailles. Les stratégies applicables au cours de la période d’élevage (période de six à sept semaines pendant laquelle les poussins d’un jour deviennent des poulets de chair) portent sur l’hygiène, la biosécurité, la vaccination et les traitements, ainsi que sur les procédures de contrôle microbiologique, visant notamment à éviter la formation de colonies. Il existe également nombre de points de contrôle critiques identifiés dans les établissements de transformation qui permettent de réduire la contamination ; il s’agit notamment des contrôles de la température (liquides de lavage et produit), des interventions chimiques, du renouvellement de l’eau, des techniques à contre-courant lors de l’échaudage et du refroidissement, ainsi que de la maintenance des équipements. Le transport et la manipulation des produits alimentaires en magasin et par le consommateur (c’est-à-dire stockage à une température adéquate et cuisson appropriée) constituent les derniers points de contrôle critiques de la chaîne allant du producteur au consommateur.

Il est important d’agir sur l’ensemble de la chaîne alimentaire pour appliquer les stratégies de réduction des risques. Ces stratégies consistent, entre autres, à faciliter l’élabo
normes efficaces de transport et de réfrigération, à œuvrer à l’adoption du Code alimentaire (model Food Code) dans tous les États fédéraux, à fournir du matériel éducatif pour les activités de santé publique au niveau de l’ensemble du pays et à coordonner l’ensemble de ces activités.

Mots-clés

Estrategias de control de *Salmonella* y *Campylobacter* en productos crudos de origen aviar

P.L. White, A.R. Baker & W.O. James

Resumen
Las toxi-infecciones alimentarias son un problema de salud pública de primer orden. La mayor parte de estas enfermedades atribuidas a las aves de corral o productos aviares tiene su origen bien en serotipos de *Salmonella* causantes de infecciones paratifoideas o bien en *Campylobacter jejuni*. Para prevenir eficazmente las toxi-infecciones alimentarias es necesario entender que los alimentos pueden contaminarse en numerosos puntos de la cadena de producción alimentaria. Dada la existencia de múltiples puntos de entrada para los patógenos, un control efectivo de la eventual contaminación de las aves exige la aplicación de estrategias combinadas, que actúen a diversos niveles durante el período de crecimiento de los pollos asaderos (broiler) y su ulterior procesado. Entre las estrategias que deben aplicarse durante el período de maduración (el intervalo de seis o siete semanas que separa a un polluelo de un día de un pollo asadero) figuran la higiene, la seguridad biológica, la vacunación y la terapia medicamentosa, además de medidas de control biológico como las destinadas a evitar la colonización. Se han identificado asimismo numerosos puntos críticos de control en las instalaciones de procesado que reducen el nivel de contaminación: controles de temperatura (de las máquinas de lavado y del producto), ajustes químicos, renovación del agua y aplicación de técnicas de flujo inverso en los escaldadores y enfriadores y, por último, un adecuado mantenimiento de la maquinaria. Un buen transporte y manipulación por parte de minoristas y consumidores (esto es, el almacenamiento a la temperatura oportuna y la cocción adecuada de los alimentos) constituyen los últimos puntos críticos de control de la cadena que lleva los alimentos de la granja a la mesa. Es importante que se apliquen medidas de control a lo largo de toda esa cadena, pues ello refuerza las estrategias de reducción de los riesgos, consistentes en: facilitar la elaboración y la aplicación voluntaria de «buenas prácticas de manejo» en el ámbito de la producción animal; aplicar sistemas de análisis de riesgos y control de puntos críticos (hazard analysis and critical control point: HACCP) en las instalaciones de procesamiento; establecer normas eficaces de transporte y refrigeración; fomentar la adopción del Código Alimentario (model Food Code) en todos los Estados federales; y coordinar las actividades de salud pública a escala nacional y enriquecerlas con material educativo.

Palabras clave
References


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