2 Hazard Identification

INTRODUCTION

Most human illnesses associated with shell egg consumption are from *Salmonella* Enteritidis (SE). Therefore, our discussions pertaining to shell eggs focus on SE. Because several *Salmonella* serotypes have been isolated from egg products,[1] both before and after pasteurization, our discussions related to liquid egg products focus more broadly on *Salmonella* spp.

THE PATHOGEN

Salmonella cause illness in humans and animals. Most *Salmonella* serotypes are naturally occurring in food animals. They may be transmitted to humans upon consumption of contaminated foods at slaughter. Food may also become contaminated with *Salmonella* by unwashed hands of infected food handlers.[2]

Virulence factors may have special significance in the ability of *Salmonella* to contaminate and survive in chicken eggs. Siderophores, which chelate iron, are necessary for the accumulation of sufficient environmental iron to allow growth of *Salmonella* in some environments. The ability to accumulate iron is especially important in the albumen of eggs. A number of virulence factors identified in non-typhoid *Salmonella* may be important determinants of the likelihood of disease in humans. To cause illness, *Salmonella* must survive the pH of the stomach and, after passage into the intestine, must attach to and invade intestinal epithelia and/or Peyer's patches.[3] Specific fimbriae, chromosome-encoded bacterial surface adhesions, hemagglutinins, and epithelial cell induction of bacterial polypeptides can promote colonization and adhesion.[4,5] Other factors, such as cytotoxins and diarrheagenic enterotoxins,[6] affect the ability of *Salmonella* to cause disease.

Epidemiology of Salmonella

Infection with *Salmonella* is estimated to cause 1.4 million illnesses, 31,000 hospitalizations, and 1,100 deaths each year in the U.S.,[7] the costs of which may be upwards of $2 billion.[8] The number of reported *Salmonella* clinical isolates in the U.S. increased from 1976 to 1988, declined from 1988 to 1992, and fluctuated between 30,000 and 40,000 from 1993 to 2000 (Figure 2-1). SE and *S.* Typhimurium have been the most common *Salmonella* serotypes associated with human illness in the U.S.[5,9-33] (Figure 2-1), accounting for half of all human salmonellosis cases.[33] During the late 1970s and early 80s, SE emerged as the leading cause of salmonellosis in the U.S. Between 1985 and 1998, 796 outbreaks caused by SE were reported to the CDC. A total of 28,689 cases of illness were associated with these outbreaks, resulting in 2,839 hospitalizations and 79 deaths.[34]

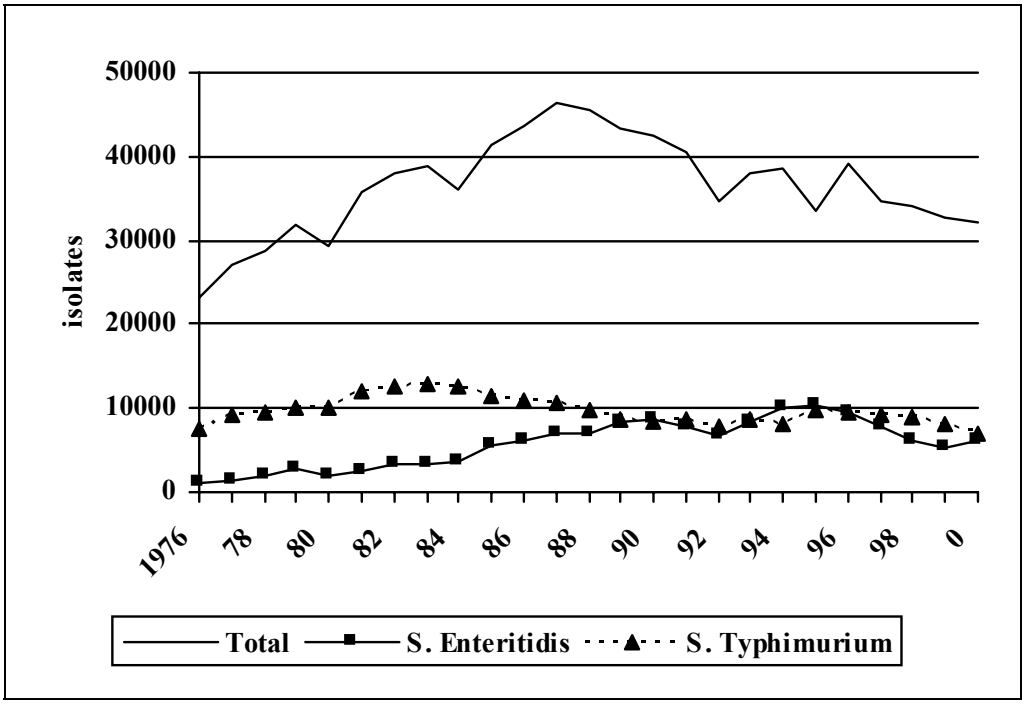

Figure 2-1 *SALMONELLA* ISOLATES FROM HUMAN SOURCES BY SEROTYPE AND YEAR, 1976-2000.[9-33]

The rate of clinical SE isolates reported to CDC increased from 0.6 per 100,000 in 1976 to 3.6 per 100,000 in 1996.[34] From 1996 to 1998 the rate of culture-confirmed SE cases declined to 2.2 per 100,000; this decline was partially reversed by an increased incidence in 2000 and 2001.[2] From the mid-1970s to the late 1980s, most SE outbreaks in the U.S. occurred in the Northeast, where they increased more than six-fold.[35,36] *Salmonella* isolates from the Mid Atlantic region declined from 1989 through 1999 (Figure 2-2), while in the Pacific region, SE isolates increased more than three-fold between 1990 and 1994.[34]

The increase in the Pacific region was concurrent with the emergence of SE phage type 4 (PT4) in poultry flocks and humans in the western U.S.[37] SE PT4, the predominant SE phage

type in other parts of the world, emerged in the egg industry in the western part of the U.S. in 1993, together with a sharp increase in the number of sporadic human SE PT4 isolates in California and Utah.[37] SE PT4 continues to be an important cause of sporadic illness, especially in the Western U.S. Of the 30 outbreaks for which an isolate was submitted to CDC for phage typing in 1998, 15 (50%) were SE PT4. Of these, 11 occurred in California, two in Utah, and one each in Hawaii and Wyoming.

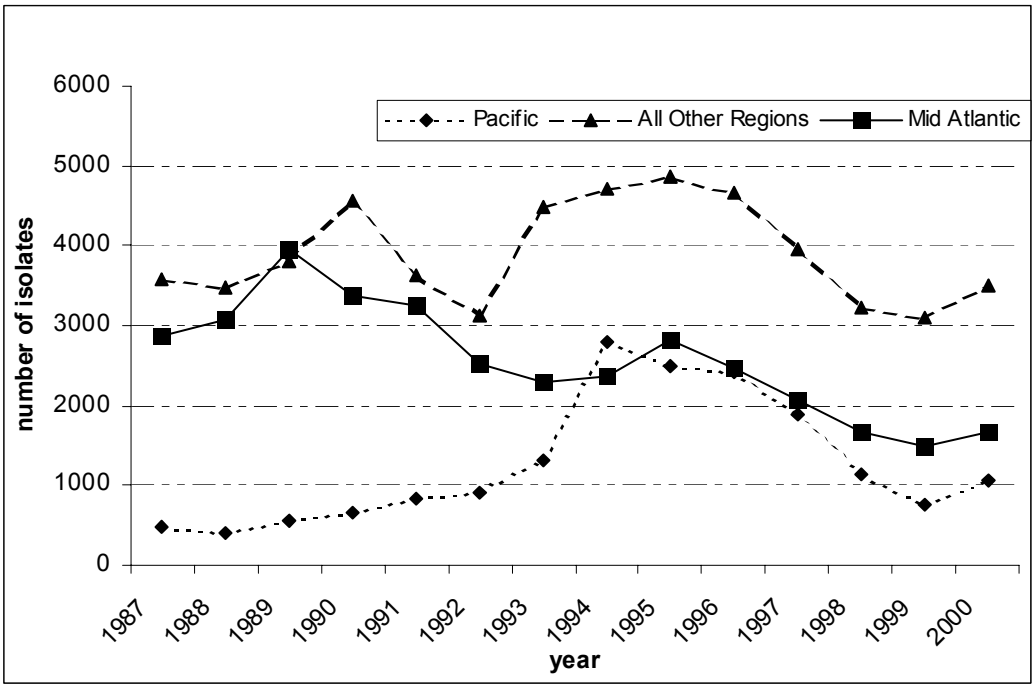

Figure 2-2 *Salmonella* Enteritidis isolates reported to the CDC by region from 1987-2000.[9-33]

Temperature is a major factor influencing the growth of *Salmonella* (TABLE 2-1). Growth for most *Salmonella* is inhibited or slowed considerably at temperatures below 15ºC and generally does not occur below 7ºC,[38;39] though some strains have been reported to grow below 5ºC.[40] *Salmonella* are susceptible to heat and killed at temperatures ≥55°C.[40] Ordinary cooking is sufficient to destroy *Salmonella*, provided sufficient time.[41]

TABLE 2-1 AFFECT OF PH AND TEMPERATURE ON GROWTH OF *SALMONELLA*.

Condition	Minimum	Optimum	Maximum
Temperature (ºC)	5.2	35–43	46.2
pH	3.8	7–7.5	9.5

Transmission of Salmonella *to humans*

Most human infections with *Salmonella* are foodborne. SE is transmitted to eggs through two routes: trans-ovarian (vertical) transmission and trans-shell (horizontal) transmission. In the

former, SE is introduced to the egg from infected ovaries or oviduct tissue before the hen lays the egg. This type of transmission is the primary route by which eggs are contaminated with SE.[42] Experimental studies suggest *Salmonella* interact with a cellular component of the preovulatory follicle in chickens.[43] The possibility of SE reaching the yolk contents through the oviduct and ultimately contaminating the albumin cannot, however, be ruled out. *Salmonella* may also penetrate the eggshell.[44-46] This secondary route of contamination can result from fecal contamination of the eggshell.

An individual consumes on average 230 eggs per year, not including eggs consumed as part of cake mixes, noodles, etc. The value of shell eggs is approximately $4 billion per year.[47] The U.S. has approximately 300 million laying hens, with an estimated value of nearly $1 billion.[47] Egg production increasingly occurs on farms with over 100,000 hens. According to the United Egg Producers (UEP),[48] the size of egg production farms has grown so that ca. 94% of U.S. eggs are produced on just over 300 farms. These large farms are known as "in-line facilities" because egg laying, cleaning, sorting, packing, and distribution occur in a streamlined process within one facility. However, many eggs are produced in traditional or "off-line facilities." In these operations, laying farms store and then ship their daily egg production to an off-site facility for processing, packing, and distribution. Although the exact processing steps vary from facility to facility, a general outline includes the following sequential steps: egg washing, rinsing, and sanitizing; drying; candling; sorting and grading; packing and palletizing; and storing in a cooler before shipping.[49]

Because of *Salmonella* thermal susceptibility, foodborne SE infection is frequently associated with consuming raw eggs and foods containing raw eggs, such as homemade eggnog, cookie batter, tiramisu, pasta, homemade ice cream, mayonnaise, Caesar salad dressing, and Hollandaise sauce. Approximately 80% of vehicle-confirmed SE outbreaks have been associated with grade A shell eggs[50] or egg-containing foods[51] (Table 2-2). Between 1993 and 1997, an average of 80% of vehicle-confirmed outbreaks were egg-associated, with a range of 68% to 95%. In 1998, of the 18 outbreaks for which a vehicle could be confirmed, 15 (83%) were associated with eggs.[31]

TABLE 2-2 FOOD VEHICLES IN 35 SE OUTBREAKS OF KNOWN CAUSE IN THE NORTHEASTERN U.S., JANUARY 1985 TO MAY 1987.[51]

Food Vehicle	Number of Outbreaks
Egg-containing	
Scrambled or fried eggs and omelets	7
Hollandaise sauce and eggs benedict	4
Commercial frozen pasta products with raw egg-cheese dishes	3
Homemade pasta dishes	3
Blenderized meals	2
Stuffing for seafood dishes	2
Rice balls and meatballs made with egg	2
Eggnog	1
Potato-egg salad	1
Cake fillings	1
Caesar salad dressing (with raw egg)	1
Total—egg-containing foods	27
Non-egg-containing (or unknown)	
Roast beef and hamburger	3
Stuffed potatoes	2
Ricotta cannoli	1
Lettuce and tomato	1
Gravy and succotash	1
Total—Not egg containing or unknown foods	8

Outbreaks caused by *Salmonella* occur most frequently in summer[2] (FIGURE 2-3). Similar seasonal patterns have been documented for SE outbreaks[36] and for *Salmonella*-positive spent hens at slaughter.[52] Warm temperatures provide an environment in which *Salmonella* can grow during the processes of production, transport, and storage.[41]

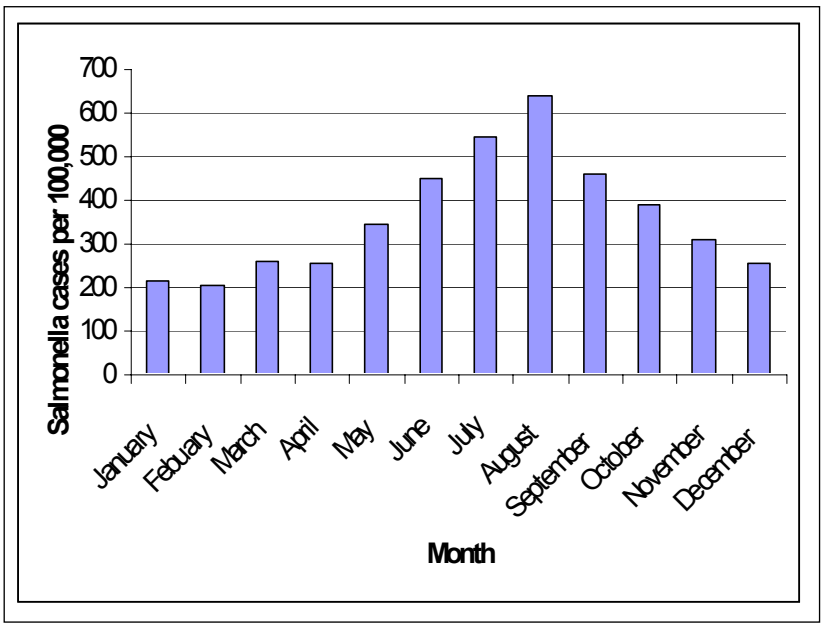

FIGURE 2-3 *SALMONELLA* CASES PER 100,000 BY MONTH, 2000.[32,53]

Disease characteristics

Salmonellosis is characterized by diarrhea, fever, abdominal pain or cramps, vomiting, headache, and nausea. The incubation period ranges from 8 to 72 hours with symptoms lasting up to a week. The severity of *Salmonella* infections varies. While most are self-limiting, some are fatal. The national average case-fatality rate among reported salmonellosis cases between 1996 and 1997 was 0.0078.[7] Fatalities occur most often in infants, the elderly, and the immunocompromised. Between 1985 and 1991, 54 SE outbreaks occurred in hospitals or nursing homes. These outbreaks accounted for 90% of all *Salmonella*-associated deaths, but only 12% of all cases, during that time. In 1995, five deaths occurred as a result of SE infection, four (80%) of which occurred in nursing homes.[28] In 1998, three (6%) of the 45 SE outbreaks occurred in nursing homes.[31] The age of patients with *Salmonella* infections follows a bimodal distribution, with most infections occurring in those at the extremes of age. The highest number of cases is seen among children[54] (
Figure 2-4). The association between salmonellosis and age, however, may be due to reporting bias because children and the elderly with diarrhea may be more frequently cultured than other age groups.[55] In addition, there may be confounding factors associated with behavioral characteristics of children.[56]

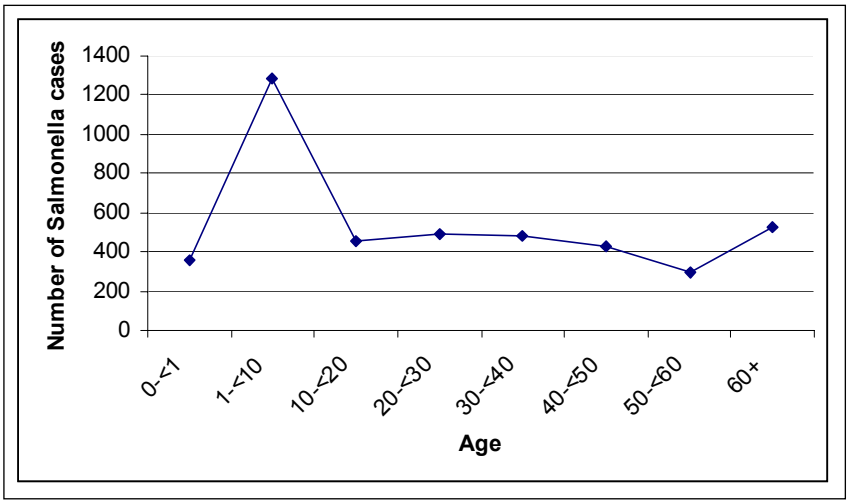

FIGURE 2-4 INCIDENCE OF *SALMONELLA* INFECTIONS BY AGE GROUP.[32,53]

Antimicrobial resistance may affect severity of illness from *Salmonella*. Patients infected with antimicrobial-resistant *Salmonella* appear more likely to be hospitalized than those infected with antimicrobial-susceptible *Salmonella*.[57] Duration of illness and hospitalization also appears positively correlated with antimicrobial-resistant *Salmonella* infections. A summary of susceptibility testing results for *Salmonella* recovered from food animals in the U.S. in 1999[58] is shown in Table 2-3. Increasing evidence indicates *Salmonella* are developing resistance to multiple antimicrobials, including frontline drugs such as ciprofloxacin and ceftriaxone.[59-61]

TABLE 2-3 ANTIMICROBIAL SUSCEPTIBILITY OF *SALMONELLA* RECOVERED FROM FOOD ANIMALS, NATIONAL ANTIMICROBIAL RESISTANCE MONITORING SYSTEM, 1999.[58]

Antimicrobial	% Susceptible
Amikacin	>99.9
Amoxicillin/clavulanic acid	88.4
Ampicillin	81.9
Apramycin	98.9
Ceftiofur	96.0
Ceftriaxone	97.7
Cephalothin	92.3
Chloramphenicol	90.1
Ciprofloxacin	100.0
Gentamicin	90.8
Kanamycin	87.7
Nalidixic Acid	98.8
Streptomycin	69.0
Sulfamethoxazole	71.1
Tetracycline	64.8
Trimethoprim/sulfa	96.6

SUMMARY

Salmonella in eggs constitute a public health threat. The hazards of interest in these risk assessments are SE in shell eggs and *Salmonella* spp. in egg products. SE can colonize the ovaries of hens and contaminate the internal contents of eggs. The shell eggs risk assessment thus focuses on SE. Because various *Salmonella* spp. have been found in egg products, the egg products risk assessment focuses on *Salmonella* spp.

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