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The Burden of Salmonellosis in the United States

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1. Introduction

Salmonellosis or *Salmonella* infection caused by nontyphoid strains is the most common foodborne disease reported from population-based, active laboratory surveillance in the United States (U.S.) (Figure 1). The overall incidence of laboratory confirmed *Salmonella*
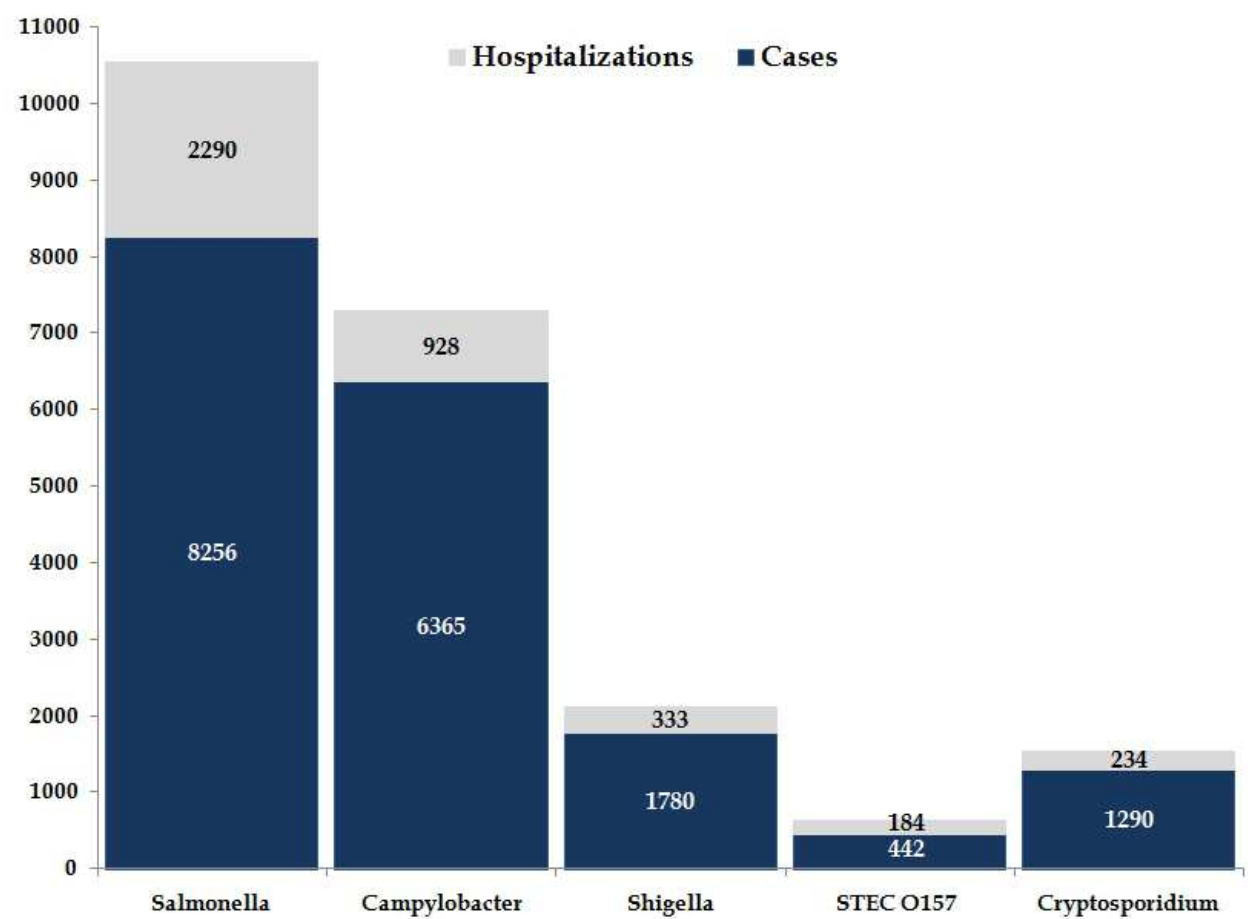

Fig. 1. Total number of laboratory-confirmed bacterial and parasitic infection cases and hospitalizations by pathogen in the United States (CDC, 2011).

infection was 17.6 cases per 100,000 persons in 2010. This was more than twice the U.S. Healthy People 2010 objective of 6.8 cases per 100,000 persons (Figure 2) (Matyas et al.,2010). Moreover, a recent report released by the Centers for Disease Control and Prevention (CDC) revealed that the incidence of *Salmonella* infections in 2010 was significantly higher than during 2006-2008 representing an increase of about 10% (95% Confidence Interval (CI), 4-17%). However, other foodborne infections, such as *Campylobacter*, *Listeria*, *Shigella*, STEC O157, *Vibrio*, and *Yersinia*, have all actually decreased during this same period (CDC, 2011). The disease burden of salmonellosis has remained substantial in the United States in spite of ongoing public health and regulatory efforts to prevent and control this infectious disease.
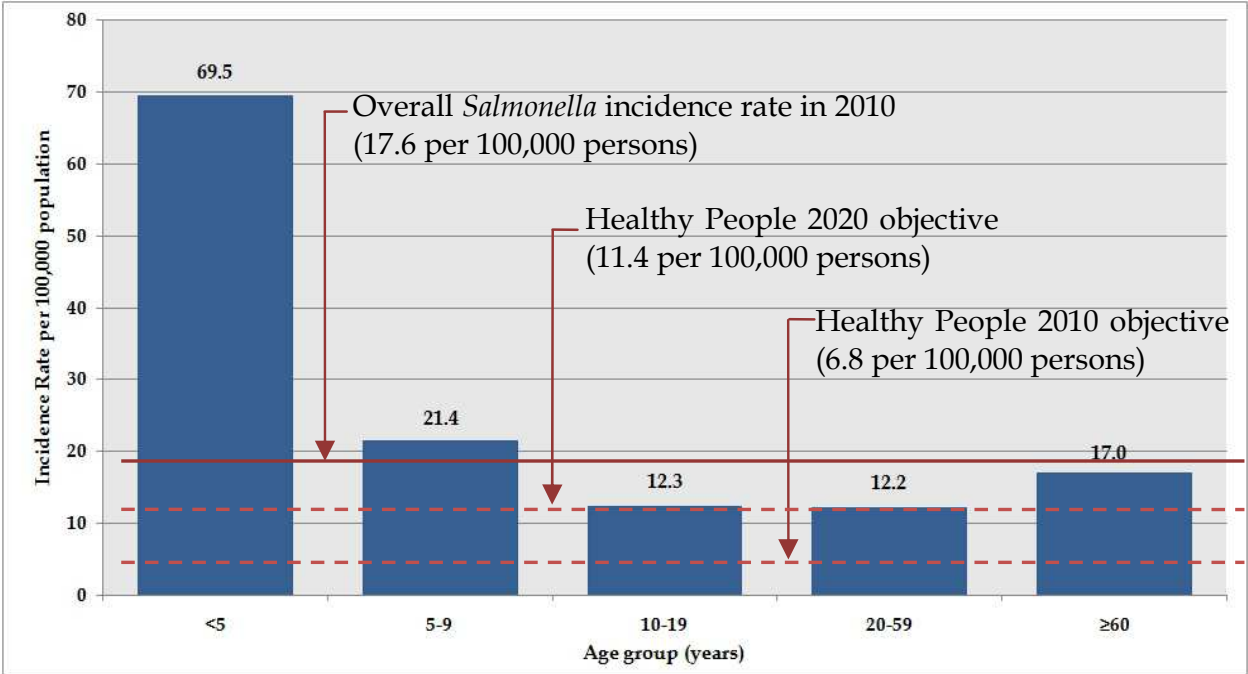

Fig. 2. Laboratory-confirmed *Salmonella* incidence rate per 100,000 population, by age group, as compared to the overall incidence rate and the national health objectives (Healthy People) for 2010 and 2020, United States, 2010 (CDC, 2011).

The present chapter discusses the trends in morbidity, mortality, and years of potential life lost attributed to human salmonellosis in the United States. In addition, this chapter provides a snapshot of U.S. public health measures and control policies that are currently in place to protect the public against *Salmonella* infection.

2. The burden of salmonellosis in the United States

Salmonellosis causes more disease burden than any other foodborne pathogen. An estimated 93.8 million cases (90% CI, 61.8-131.6 million) of gastroenteritis caused by *Salmonella* species occur globally each year and of these, nearly 80.3 million cases are foodborne (Majowicz et al., 2010). In the United States, an estimated 1 million incident cases of human salmonellosis occur annually (Scallan et al., 2011); however, only a small portion of these cases are recognized clinically (*see section 2.2*). In industrialized countries as few as 1% of clinical cases are actually reported (Heymann, 2008). Collectively, *Salmonella* infections in the United States account for roughly 19,336 hospitalizations, 17,000 quality adjusted life

years lost (QALYs), and $3.3 billion in total medical expenditures and lost productivity each year (Batz et al., 2011).

2.1 Clinical manifestations, serotypes, and outbreaks

Salmonella gastroenteritis is usually a self-limited disease in which the symptom of fever typically resolves within 48 to 72 hours and diarrhea within three to seven days. Complications from the infection may include severe dehydration, shock, collapse, and/or septicemia. Symptoms are usually more severe among infants, young children, elderly, and those who are immune-compromised (Scallan et al., 2011).

Although there are many serotypes of *Salmonella* that are pathogenic to both humans and animals (i.e., approximately 2,500 serotypes have been identified), the vast majority of human *Salmonella* isolates are serotype *S. enterica* subsp. *enterica* (Heymann, 2008). Serovars Typhi and Paratyphi of this serotype, *S. enterica* subsp. *enterica,* are the etiologic agents that cause typhoid and paratyphoid fevers. These types are also common, but are generally found in developing countries, such as those in South America, Africa, and parts of Asia (Heymann, 2008). In developed countries where there is active, coordinated foodborne disease surveillance, other serovars such as Typhimurium and Enteritidis are frequently reported.

Sixty to eighty percent of all human salmonellosis cases in the United States occur intermittently and sporadically throughout the population. Clusters of large outbreaks in restaurants, institutions for children, hospitals, and nursing homes have occurred recently and remain major public health threats. These outbreaks are usually the product of contamination from a production source, such as chicken farms, feed blending mills, and slaughterhouses. One of the more well-known *Salmonella* outbreaks in the United States occurred in 2010. This outbreak resulted from contamination in the food production chain, leading to a massive egg recall of over half a billion eggs and more than 2,000 reported cases of *Salmonella*-related illness (Hutchison, 2010). Although less common, outbreaks from food handling by an ill person or carrier have been reported in recent years (Cruickshank et al., 1987; Khuri-Bulos et al., 1994). For instance, in 2000 an ill food handler in a bakery that supplied hamburger buns to restaurants was found responsible for an outbreak among several burger restaurants across Southern California and Arizona. This outbreak was atypical in that it resulted from consumption of commercially distributed bread, which is a highly unusual vehicle for most foodborne infectious agents (Kimura et al., 2005).

Outbreaks from person-to-person transmission can also be of particular concern, especially among hospital workers who have the potential to spread the bacterium with their hands or through contaminated instruments. Outbreaks of *Salmonella* infection have occurred in places like maternity wards where staff members with contaminated hands and/or the use of contaminated medical instruments result in the transmission of *Salmonella* to babies and mothers (Rowe et al., 1969). In 2008, an outbreak strain of *Salmonella* serotype Tennessee occurred in a neonatal intensive care unit in the United States, where limited access to sinks for hand washing likely facilitated the transmission to infants (Boehmer, 2009).

2.2 Salmonellosis incidence – FoodNet data

Based on FoodNet surveillance data (*see section 4.1*) for nine selected foodborne pathogens from 10 states and three federal agencies (CDC, U.S. Food and Drug Administration, and U.S. Department of Agriculture), a total of 19,089 laboratory-confirmed cases of foodborne infections, 4,247 hospitalizations, and 68 deaths were identified for the year 2010 in the U.S.

(CDC, 2011). Of the nine pathogens monitored, including *Campylobacter*, *Listeria*, *Salmonella*, *Shigella*, STEC O157, *Vibrio*, *Yersinia*, *Cryptosporidium*, and *Cyclospora*, salmonellosis was the most common infection reported and had the highest number of associated hospitalizations and deaths. A total of 8,256 infections (17.6 illnesses per 100,000 persons); 2,290 hospitalizations; and 29 deaths were attributed to this pathogen in 2010. Ninety-two percent (7,564 out of 8,256) of these isolates were subsequently serotyped through PulseNet (*see section 4.1*), with Enteritidis (22%), Newport (14%), and Typhimurium (13%) representing the most common serotypes. The FoodNet data indicate that the rate of infection from *Salmonella* remains substantially high and has not declined for over a decade, as compared to the other eight foodborne pathogens tracked through FoodNet. These data support ongoing control efforts in the United States that target *Salmonella*, particularly in response to the costs associated with treatment of this infection – approximately $365 million in direct medical costs each year (CDC, 2011).

2.3 Salmonellosis-related mortality

Current estimates indicate that there are about 155,000 salmonellosis-related deaths each year worldwide (Majowicz et al., 2010); between 400-600 of them are in the United States (Mead et al., 1999; CDC, 2008). While risk of death and actual deaths from salmonellosis are not typically common in the general population, the infection can be particularly virulent in vulnerable groups, especially among young children, older adults, and those who are immune-compromised (*see section 3*).

Table 1 presents the most updated analysis of multiple cause-of-death (MCD) data based on death certificates in the United States. From 1990 to 2007, there were 1,372 nontyphoidal *Salmonella*-related deaths. Among these reported deaths, *Salmonella* was listed as an underlying cause of death on 785 (57.2%) death certificates and as an associated cause of death on 587 (42.8%) death certificates. Fifty-six deaths occurred in 2007 alone, resulting in an age-adjusted mortality rate of 0.018 per 100,000 population (95% CI, 0.013-0.022). The average age-adjusted mortality rate over the entire study period, from 1990 to 2007, was 0.028 per 100,000 population (95% CI, 0.027-0.030; n=1,372). This represents a total of 21,417 years of potential life lost (Table 1).

Between 1990 and 2006 the age-adjusted mortality rate for human salmonellosis declined from 0.06 per 100,000 population (95%CI, 0.05-0.07; n=136 deaths) to 0.01 per 100,000 population (95%CI, 0.01-0.02; n=45 deaths). The variance between deaths and incidence, in terms of trends over the past decade show that deaths have decreased (Cummings PL et al., 2010), but incidence has increased (CDC, 2011). This difference could potentially be the result of better medical treatment or other contributing factors accounting for the decline in deaths. In 2007, however, a slight increase (albeit not significant) in the frequency and rate of *Salmonella*-related deaths was observed (Figure 3). The mean age of decedents with *Salmonella* infection listed on their death certificate for the period 1990-2007 was 63.1 years. Overall, males were more likely than females to have *Salmonella* listed as a cause of death (either underlying or associated) on their death certificate and have more years of potential life lost – 13,447 years for males versus 7,970 years for females (Table 1). Infants (< 1 year of age) and older adults (> 65 years of age) had the highest frequency of *Salmonella*-related deaths over the 18-year period (Table 1). The highest age-specific mortality rates during this period were observed among infants (0.086 per 100,000 population), those aged 75-84 (0.160 per 100,000 population), and those 85 years and older (0.314 per 100,000 population). Asian, black, and Hispanic race/ethnicity had higher rates of mortality from Salmonella infection as compared to whites.

	Frequency (N%)	Age-Adjusted Mortality Rate (95% CI)	Age-Adjusted Rate Ratio (95% CI)	Age-adjusted Rates of Potential Life Years Lost
Sex				
Female	583 (42.5%)	0.021 (0.019-0.022)	Referent	7,970
Male	789 (57.5%)	0.038 (0.035-0.041)	1.84 (1.68-2.02)	13,447
Race/Ethnicity†				
White	893 (65.1%)	0.023 (0.021-0.024)	Referent	9,768
Asian/Pacific Islander	76 (5.5%)	0.059 (0.045-0.073)	2.63 (2.45-2.82)	1,256
Black	279 (20.3%)	0.057 (0.050-0.064)	2.53 (2.36-2.72)	7,095
Hispanic	116 (8.5%)	0.031 (0.025-0.038)	1.39 (1.28-1.50)	3,050
Native American	7 (0.5%)	0.025 (0.005-0.045)	1.11 (1.02-1.21)	173
Age group (years)*†		**Age-Specific Mortality Rate**		
<1	61 (4.4%)	0.086 (0.064-0.107)	--	4,575
1-4	18 (1.3%)	0.006 (0.003-0.009)	--	1,315
5-14	12 (0.9%)	0.002 (0.007-0.003)	--	797
15-24	22 (1.6%)	0.003 (0.002-0.005)	--	1,204
25-34	85 (6.2%)	0.012 (0.009-0.014)	--	3,797
35-44	91 (6.6%)	0.012 (0.009-0.014)	--	3,236
45-54	128 (9.3%)	0.020 (0.017-0.024)	--	3,262
55-64	134 (9.8%)	0.030 (0.025-0.035)	--	2,004
65-74	243 (17.7%)	0.073 (0.064-0.082)	--	1,227
75-84	342 (24.9%)	0.160 (0.143-0.177)	--	0
>85	235 (17.1%)	0.314 (0.274-0.354)	--	0
Total	1,372	0.028 (0.027-0.030)	N/A	21,417

Note: 95% CI = confidence interval; Years of Potential Life Lost were calculated by subtracting the age in years at the time of death from 75 years. *Mortality rates are age-specific rates, not age-adjusted rates. †Numbers may not add up to total, due to missing data.

Table 1. Age-adjusted nontyphoidal *Salmonella*-related mortality rates per 100,000 population and mortality rate ratios by sex, race/ethnicity and age group, United States, 1990-2007.

Asians had the highest age-adjusted rate ratio of 2.63 (95% CI, 2.45-2.82; n=76 deaths) relative to whites, the referent group (Table 1). While whites had the highest absolute number of deaths (n = 893), they had the lowest age-adjusted mortality rate (0.023 per 100,000 population; 95% CI, 0.021-0.024). Reasons for disparities in *Salmonella* mortality based on gender and race/ethnicity have been discussed in a previously published paper (Cummings PL et al., 2010). California and New York had the highest number of deaths (n=219 and n=105, respectively), but relatively low age-adjusted mortality rates (0.04 per 100,000 population, 95% CI, 0.04-0.05 and 0.03 per 100,000 population, 95% CI, 0.02-0.04, respectively). Although Hawaii and District of Columbia had smaller numbers, they had the highest age-adjusted

mortality rates during 1990-2007 (0.08 per 100,000 population, 95% CI, 0.04-0.12; n=18 and 0.08 per 100,000 population, 95% CI, 0.02-0.13; n=8, respectively).

Methods used in this updated analysis are similar to those previously described in Cummings PL et al., 2010. Briefly, years of potential life lost (YPLL) were calculated by subtracting the age in years at the time of death from 75 years (Gardner, 1990). Deaths were defined as any observation listed as either the underlying cause or the associated cause of death with the following International Classification of Diseases, 9th revision (ICD-9) and 10th revision (ICD-10) codes: 003.0-003.9 and A02.0-A02.9, respectively. These ICD codes included infection or foodborne intoxication due to any *Salmonella* species, other than serovars Typhi and Paratyphi, which are the microbial agents that cause typhoid and paratyphoid fevers. Since these latter conditions are rare in the United States and predominately occur in developing countries (e.g., countries in Southeast Asia, Africa, and South America), serovars Typhi and Paratyphi were excluded from the analysis.
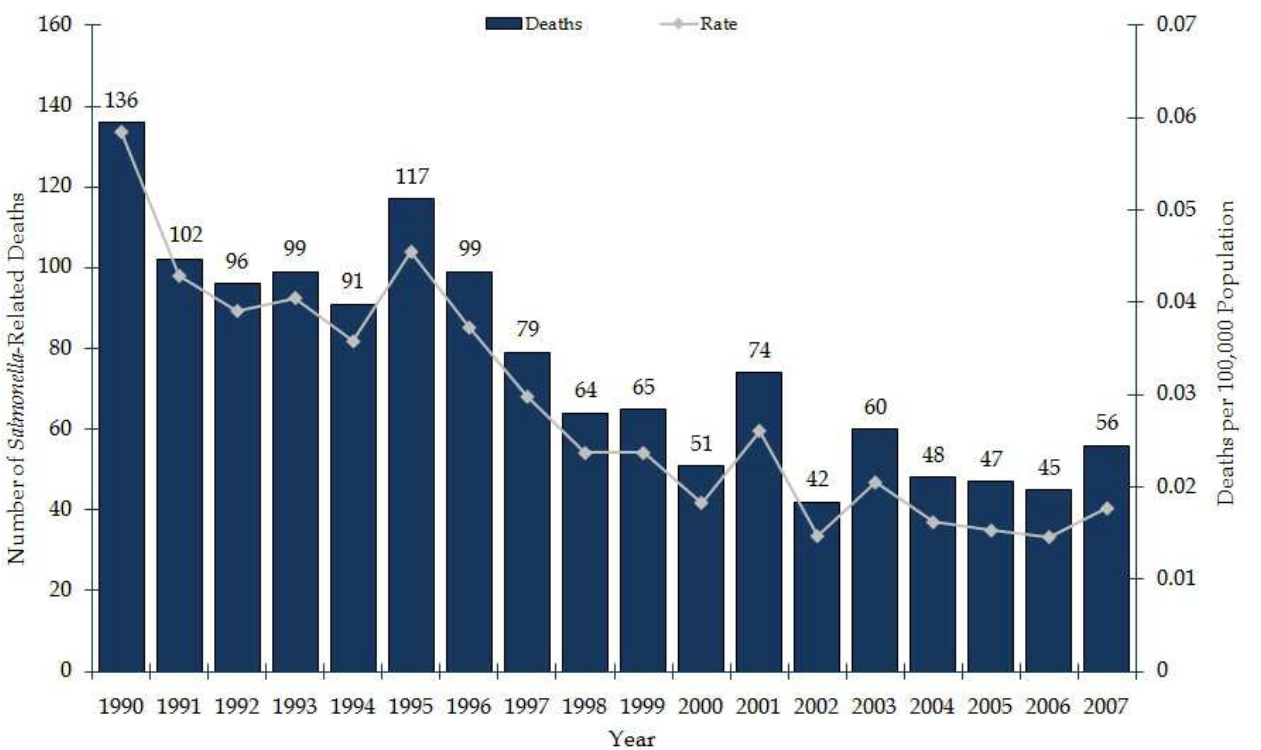

Fig. 3. Number of nontyphoidal *Salmonella*-related deaths and age-adjusted mortality rates per 100,000 population by year, United States, 1990-2007.

2.4 Changing trends in factors that may contribute to human salmonellosis

Although mortality rates are important indicators of health status, they often do not tell the entire story. Factors such as the aging population; increased burden of chronic diseases that can suppress immunity; and an increasingly global market in meats, poultry, vegetables, fruits, farm animals, and pets (e.g., chicks and reptiles) are all emerging influences that can potentially amplify the risk and burden of human salmonellosis in the United States.

2.4.1 An aging population and increased burden of chronic disease

As the present generation of baby boomers (those born between 1946 and 1964) reach age 65 and older, the trend in *Salmonella*-related deaths is expected to change, suggesting that more deaths could ensue, given that older adults frequently experience more severe infections and require hospitalization more often from this foodborne illness than younger adults (Kennedy et al., 2004). Trends showing increased chronic disease prevalence in the population for such conditions as cancer, autoimmune disorders, and other diseases requiring treatment with immune-suppressive therapies parallel the aging of the population and foreshadow the continual burden of human salmonellosis in the United States (Altekruse et al., 1997).

2.4.2 An increasingly global market

Today's global market in meats, poultry, vegetables, fruits, farm animals, and pets, represents potential sources of *Salmonella* contamination that are complex and sometimes difficult to control. For example, in 2008 there was a multi-state outbreak of *Salmonella* Typhimurium associated with frozen vacuum-packed rodents that are used to feed snakes (Fuller et al., 2008). This occurrence represents a rare, but wide-spread outbreak associated with commercially distributed rodents. Likewise, the illicit selling and importation of many animals from abroad have caused several unanticipated salmonellosis outbreaks, as well as agricultural problems for the region. In Los Angeles County, the illegal selling of red-eared slider turtles (< 4 inches in diameter) has become an important public health problem. Because caring for these animals is exceedingly difficult, they are often abandoned or dumped by their owners into wildlife preserves and adquaducts. A local animal control agency in Los Angeles County found that an increasing number of turtles have been dumped over the years; they impounded over 6,000 illegally sold, undersized red-eared slider turtles from 2000-2007 (unpublished data). The upward trend in the abandonment of turtles and the turtles' high fecundity rates may also increase the risk of transmission to native species (Perez-Santigosa et al., 2008). Nearly 10% of all reported cases of human salmonellosis in Los Angeles County have been attributed to direct or indirect contact with reptiles, namely the red-eared slider turtle, the most common reptile source found in more than 50% of these cases (LACDPH, 2008). Continual monitoring and targeted improvements to regulate the illegal selling of these animals remain key control measures for protecting the public against acquiring *Salmonella* infections from reptiles.

3. Salmonellosis in vulnerable groups with comorbid conditions

Clinical evidence suggests that infection with nontyphoid *Salmonella* often results in more severe manifestations of clinical disease than from any other foodborne pathogen (Helms et al., 2006). Comorbid health conditions and their related immuno-suppressive treatments may be particularly problematic, especially among vulnerable groups at high risk of progressing to severe forms of salmonellosis (Trevejo et al., 2003; Cummings PL et al., 2010). For example, those with HIV/AIDS, certain types of cancers (e.g., leukemia, bone marrow), or autoimmune disorders are at significantly greater risk for death, as compared to persons without these conditions. In the updated analysis of *Salmonella*-related mortality as described in *section 2.3*, a matched case-control study showed that HIV (matched odds ratio (MOR) =7.42; 95% CI, 5.26-10.47), leukemia (MOR=2.95; 95% CI, 1.48-5.88), connective tissue disorders (MOR=2.36, 95%CI, 1.42-3.93), lupus (MOR=3.83; 95% CI, 1.72-8.55), and

rheumatoid arthritis (MOR=2.24; 95% CI, 1.10-4.55) were more likely to be reported on death certificates with *Salmonella* infection listed as an underlying or associated cause of death than controls when matched on age, sex, and race/ethnicity (Table 2). Other conditions found to be listed with *Salmonella* infection on death certificates included: septicemia; various types of renal failure and disorders of fluid, electrolyte, and acid-base balance; and sickle-cell disorders (Table 2). The matched analysis examined comorbid conditions most often listed on death certificates of those who died from *Salmonella* infection, as either an underlying cause or associated cause of death. Table 2 lists these diseases within a broader category (e.g., all types of cancer, all types of renal failure) and their corresponding ICD codes. For example, Leukemia is one type of cancer that affects the bone marrow.

Comorbid condition	ICD-9 and ICD-10 codes (respectively)	Salmonella-related deaths (N=1,371),[a] N(%)[b]	Matched control deaths (N=5,484), N(%)[b]	Matched odds ratios (95%CI)
Alcohol and drug abuse	303-305, K70, F10-F19	40 (2.92)	237 (4.32)	0.65 (0.46-0.92)
Cancer (all types)	140-239, C00-D48	192 (14.00)	1,373 (25.04)	0.47 (0.40-0.56)
- Malignant neoplasm (bone, connective tissue, skin, breast)	170-175, C40-C49	13 (0.95)	102 (1.86)	0.50 (0.28-0.90)
- Malignant neoplasm (digestive organs, peritoneum)	150-159, C15-C26	33 (2.41)	336 (6.13)	0.37 (0.26-0.54)
Cancers affecting bone marrow (all types)	200, 203-205, C85, C88, C90-C92	46 (3.36)	92 (1.68)	2.01 (1.41-2.87)
- Leukemia	204, C91	14 (1.02)	19 (0.35)	2.95 (1.48-5.88)
Connective tissue disorders (all types)	710, 714, M05-M06, M08, M32-M35	24 (1.75)	43 (0.78)	2.36 (1.42-3.93)
- Lupus*	695.4, 710, L93, M32	12 (0.88)	14 (0.26)	3.83 (1.72-8.55)
- Rhumatoid arthritis	714, M05-M06, M08	12 (0.88)	22 (0.40)	2.24 (1.10-4.55)
Diabetes	250, E10-E11, E14	109 (7.95)	422 (7.70)	1.04 (0.83-1.30)
Diseases of the circulatory system	390-459, I00-I99	674 (49.16)	2,938 (53.57)	0.82 (0.73-0.93)
Endocrine, nutritional, metabolic diseases, and immunity disorders (all types)	240-279, E00-E90	242 (17.65)	669 (12.20)	1.56 (1.32-1.83)
- Disorders of fluid, electrolyte, acid-base balance	276, E87	57 (4.16)	78(1.42)	3.03 (2.12-4.31)

Comorbid condition	ICD-9 and ICD-10 codes (respectively)	Salmonella-related deaths (N=1,371),[a] N(%)[b]	Matched control deaths (N=5,484), N(%)[b]	Matched odds ratios (95%CI)
Flu/Pneumonia (organism unspecified)	480-488, J10-J18, P23	107 (7.80)	445 (8.11)	0.95 (0.76-1.18)
Diseases of the digestive system (all types)	520-579, K00-K93	246 (17.94)	447 (8.15)	2.46 (2.08-2.92)
- Liver diseases	570-573, K70-K77	72 (5.25)	201 (3.67)	1.51 (1.14-2.00)
HIV	042, B20-B24	133 (9.70)	121 (2.21)	7.42 (5.26-10.47)
Renal Failure (all types)	580-589, N17-N19	197 (14.37)	374 (6.82)	2.38 (1.96-2.87)
- Acute renal failure	584, N17	74 (5.40)	71 (1.29)	4.31 (3.09-6.01)
- Chronic renal failure	585, N18	26 (1.90)	106 (1.93)	0.98 (0.63-1.52)
- Unspecified renal failure	586, N19	96 (7.00)	203 (3.70)	2.00 (1.55-2.58)
Septicemia (including other septicemia)	038, A40.9, A41	193 (14.08)	304 (5.54)	2.73 (2.25-3.32)
Sickle-cell disorders	282, D57	13 (0.95)	6 (0.11)	10.2 (3.16-32.91)

[a] One case was excluded due to missing variables. [b] Numbers may not add up to total due to missing data.

Table 2. Comorbid conditions associated with nontyphoidal *Salmonella* mortality in the United States, 1990-2007.

4. Current surveillance efforts, prevention, and next steps

4.1 Current surveillance efforts in the United States

In the United States, surveillance for *Salmonella* infections has been an ongoing effort since 1996. Managed by the CDC, the Foodborne Diseases Active Surveillance Network (FoodNet) collects active, population-based surveillance data on laboratory-confirmed infections for nine different pathogens that are commonly transmitted through food (as listed in *section 2.2*). These pathogens include *Campylobacter*, *Listeria*, *Salmonella*, *Shigella*, STEC O157, *Vibrio*, *Yersinia*, *Cryptosporidium*, and *Cyclospora* (the latter two are parasites). This surveillance effort includes 10 state health departments (i.e., California, Colorado, Connecticut, Georgia, Maryland, Minnesota, New Mexico, New York, Oregon, Tennessee), the U.S. Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS), the Food and Drug Administration (FDA), and the CDC. The total surveillance area accounts for approximately 15% of the United States population, representing about 46 million people.

The national *Salmonella* database in PulseNet, which is the national molecular subtyping network for foodborne disease surveillance, was established by the CDC to subtype

bacterial foodborne pathogens. PulseNet routinely subtypes *E. coli* O157:H7, nontyphoid *Salmonella* serotypes, *Listeria* monocytogenes, and *Shigella*. The database encompasses 46 states, two local public health laboratories, and the food safety laboratories of the Food and Drug Administration and the U.S. Department of Agriculture. The national database of pulsed-field gel electrophoresis (PFGE) for foodborne bacterial pathogens helps track potentially unrelated cases in isolated geographic areas and identifies outbreak strains.

4.2 Salmonellosis transmission, prevention, and next steps

The most common mode of *Salmonella* transmission is through the ingestion of the bacterium in food derived from an infected animal or contaminated by feces of an infected animal or person (Mead et al., 1999). This includes raw and undercooked eggs or egg products, raw milk or milk products, poultry, meat, contaminated water, and any other food item that uses potentially contaminated ingredients. Farm animals used to produce these ingredients can become infected by eating feed and fertilizers prepared from contaminated meat scraps and bones. The infection can then spread by bacterial multiplication during rearing and slaughter. This chain of transmission can eventually lead to person-to-person fecal-oral transmission when a person comes in contact with contaminated feces and transmits it to others through a vehicle (e.g., food) or by direct transmission.

Other sources of transmission may occur from handling *Salmonella*-contaminated pet turtles, iguanas, chicks, and unsterilized pharmaceuticals of animal origin. Contact with pet turtles and other reptiles can be a very serious health risk to infants, small children, and adults with weakened immune systems (LACDPH, 2008). Hand-to-mouth and object-to-mouth behaviors are common among young children and can increase their risk for contracting salmonellosis. This resulted in a nationwide ban on the sale of turtles less than four inches in diameter in 1975 (US-CFR, 2010).

More recently, there have been several outbreaks of salmonellosis traced to consumption of raw fruits and vegetables, generally contaminated from manure on the outer surface of the fruit or vegetable. Manure contamination can be from the farm or during packing (Harris et al., 2003). In 1999, a multi-state outbreak of *Salmonella enterica* serotype Baildon (a rare serotype) was associated with raw, domestic tomatoes in the United States (Cummings K et al., 2001). This large outbreak resulted in 86 confirmed cases of salmonellosis.

Since there are several species of domestic and wild animals that can harbor *Salmonella* (e.g., poultry, swine, cattle, rodents and pets such as iguanas, tortoises, turtles, terrapins, chicks, dogs and cats), control policies and measures for preventing *Salmonella* infection are often more complex than for other foodborne pathogens. The fact that humans can also carry this bacterium either as mild, unrecognized cases or as convalescent carriers (i.e., those who have recovered from symptomatic illness, but are still capable of transmitting the pathogen to others) also contributes to this complexity. As carriers, humans can be particularly effective in spreading the disease in the population. Fortunately, chronic carrier states are rare in humans; they are, however, prevalent in animals.

Given that the most common mode of transmission is from handling and consuming infected food, the risk of exposure to salmonellosis can occur at multiple points in the food distribution chain, including retail food establishments and homes. Since the food distribution chain directly and indirectly affects all individuals, vigilant monitoring and regulation at multiple points in the chain are vital.

4.2.1 Food distribution chain

Salmonella prevention can be implemented in a number of ways, one of which is through environmental or system policies that improve regulation of potential sources of contamination. For example, the U.S. Department of Agriculture's Food Safety and Inspection Service currently recommends establishing facilities for irradiation of meats and eggs (USDA-FSIS, 2005). In addition, the need for improved sanitation inspection and supervision of abattoirs, food-processing plants, feed-blending mills, and egg grading stations is growing, as these are top sources of contamination for common foodborne pathogens in the United States (Batz *et al.*, 2011). Multiple regulatory outlets are currently responsible for monitoring different aspects of the U.S. food distribution chain. The Food and Drug Administration is responsible for the safety of approximately 80% of the nation's food supply, while other government entities, including the U.S. Department of Agriculture oversee the remainder. In covering such a broad enforcement responsibility, these agencies are continuously striving to reduce gaps in coordination and frequently collaborate on multiple efforts to ensure food safety. The World Health Organization (WHO) recommends strong communication, infrastructure, and coordination efforts among private, local, and federal regulatory sectors. The WHO also recommends the establishment of enhanced food safety standards in feed control regulation; cleaning and disinfection; vector control; and adequate cooking or heat-treating (including pasteurization or irradiation) of animal-derived foods prepared for animal consumption (e.g., meat or bone or fishmeal and pet foods). U.S. agencies follow these standards.

The regulatory policies currently in place have been developed over many years in the United States. Starting in the early 1990s, farm-to-table egg safety efforts were developed by the Food and Drug Administration and the USDA Food Safety and Inspection Service (FSIS). Over the years, FSIS gained more regulatory authority in enforcing laws, including the Federal Meat Inspection Act (FMIA), the Poultry Products Inspection Act (PPIA), and the Egg Products Inspection Act. These particular laws or regulations required federal inspection and regulation of meat, poultry, and processed egg products prepared for distribution. In conjunction with these laws, the Food and Drug Administration and the FSIS conducted a joint *Salmonella Enteritidis* risk assessment in 1998. This assessment found that a broad-based policy encompassing multiple interventions from farm-to-table is more likely to be effective in eliminating egg-associated salmonellosis cases than a single policy directed solely at one stage of the production-to-consumption continuum.

The lessons learned from the Food and Drug Administration (FDA) and the FSIS joint evaluation efforts contributed to the development and implementation of the FDA's new food safety strategy – coined as the "new egg rule" (Figure 4). This rule is considered very comprehensive and is aimed at preventing *Salmonella Enteritidis* in shelled eggs during production, storage, and transportation. Ironically, (as mentioned in section 2.1) one of the largest Salmonella outbreaks in U.S. history that led to a massive recall of about half a billion eggs and more than 2,000 reported illnesses occurred just prior to implementation of these new regulations during the summer of 2010 (Hutchison, 2010). The new egg rule requires production plants to implement intense rodent control, limits on contamination from people and equipment, regular egg tests, egg storage temperatures that retard *Salmonella* growth, and a requirement that egg producers maintain records documenting their compliance with these regulations. Modeled after several existing state programs (e.g., Pennsylvania Egg Quality Assurance Program), the new egg rule will, according to some farms, increase costs of production to about a penny per dozen (Hutchison, 2010). However, the Food and Drug

Administration projected an average annual cost of about $24,100 per farm site, which translates into about $0.30 cents per *layer* (i.e., a layer is a chicken that produces eggs) (USDA-APHIS, 1999). One of the benefits of this new egg rule, if properly regulated, is that it can potentially outweigh the healthcare-associated costs of treating salmonellosis. The Food and Drug Administration expects that the rule will decrease *Salmonella* in plants by 60%, save more than 30 lives each year, and avert more than 79,000 cases of salmonellosis annually (USDHHS, 2009). The preventive measures that were included in this new rule have been demonstrated to be relatively effective for preventing the spread of *Salmonella Enteritidis* (USDHHS, 2009). Moreover, shelled eggs were targeted by these measures because they are the predominant source of foodborne *Salmonella Enteritidis*-related outbreaks in the United States (USDHHS, 2009).

Fig. 4. Consumer health information guide released by the Food and Drug Administration and the U.S. Department of Agriculture on September 2010 outlining the new egg rule.

One of the anticipated hurdles of the new egg rule may be implementation barriers, such as the limited capacity of smaller facilities to comply with the required preventive measures. Smaller farms may not be as prepared as larger farms to meet the rule's requirements during the initial stages of implementation. More specifically, they may be less likely to have adequate refrigeration capacity, effective rodent control, an efficient biosecurity program, and the necessary measures in place to limit laying hens' exposure to manure on building floors. The Food and Drug Administration (FDA) has anticipated this need to assist smaller farms. Currently, there is an FDA exemption in place for producers with small flocks (i.e., less than 3,000 laying hens). The agency's strategic decision to target the largest producers is based on its goal of having the greatest impact in terms of farm-to-table distribution of eggs. This is a reasonable approach, at least in the initial years of implementation. Eventually, consideration for expanding this rule to apply to smaller farms may be beneficial.

4.2.2 Restaurant and retail food environments

United States, California

On July 1, 2011, in the state of California (U.S.A.), a food handler card law was implemented. This law requires that all employees of retail food establishments who prepare, store or serve food, must have a California Food Handler Card. This regulation applies to servers, chefs/head chefs/cooks/head cooks, bartenders, bussers (i.e., those who help assist the server by cleaning tables and other duties), and hosts and hostesses who handle food. Supervisors, including the general manager, may also need to carry the card if they do not already have a Food Protection Manager Certification. To receive a card or become certified, a person must take a basic food safety training course and pass a test with a score of 70% or better; the card is only valid for up to three years. Thus, food service employees must take the course every three years. Currently, the U.S. National Restaurant Association (ServSafe® California Food Handler Program), ProMetric, and the U.S. National Registry for Food Safety Professionals are the only three providers that can issue cards within California.

Implementation of this program demonstrates the importance of preventive measures at the restaurant and/or retail level. For instance, not all food handlers at the different stages of food preparation in a given establishment may be entirely aware of raw products that are contained in certain foods, dishes, or recipes handed down to them by restaurant management or by other food handlers. A few examples include raw or partially cooked eggs (e.g., 'over easy' or 'sunny side up,' eggnogs, and homemade ice cream), the use of dirty or cracked eggs, pooled eggs (i.e., combining multiple eggs together), and dishes containing eggs that are not immediately cooked. Generally, all of these practices should be avoided or at least substituted with the use of pasteurized egg products (or irradiated egg products) if use of raw eggs is necessary for a recipe.

Other preventive measures should include prohibiting individuals with diarrhea from food preparation. Known *Salmonella* carriers may require isolation or long-term monitoring and should definitely be discouraged from preparing food for others as long as they shed the organism.

Los Angeles County, California (U.S.A.)

In December 1997, in response to increased media attention of foodborne illness stemming from unsafe and unhygienic food handling practices in restaurants, the County of Los Angeles government passed an ordinance that focused on increasing transparency and consumer awareness of hygiene and sanitation practices at restaurants and other retail food establishments through restaurant inspections (Fielding, 2008; Zhe Jin and Leslie, 2003). Prior to its passage, the Department of Health Services routinely conducted hygiene inspections among restaurants in Los Angeles County. However, the results of these inspections were not made public. Thus, under the new mandate, inspection results were required to be posted as a letter grade corresponding to an aggregated inspection score (i.e., 90-100 = A, 80-89 = B, 70-79 = C, etc.) (Figure 5). Specifically, it required that restaurants and other retail food facilities publicly post their assigned letter grade (using a standardized-format grade card, see Figure 5), typically near the entrance, within five feet of the point of entry so the score would be visible to patrons (Simon, et al. 2005; Zhe Jin and Leslie, 2003).

A month prior to the adoption of the ordinance, as a direct response to the need for transparency and consumer awareness, the County of Los Angeles Board of Supervisors requested that the Department of Health Services, which at the time included the Department

of Public Health, draft a 17-point action plan to enhance the existing restaurant inspection process (Fielding, 2008). The recommendations outlined by this plan laid the groundwork for the ordinance. The plan called for establishing inspection scoring criteria, adopting letter grading, and increasing transparency of inspection results (Fielding, 2008). It also specified several enhancements to the existing program, such as requiring Environmental Health (EH) staff to undergo rigorous training to learn the new inspection procedures; restaurant managers and workers receive food safety training; a 24-hour restaurant hotline be established so that the public could report complaints about food establishments; and development of a new inspection schedule (Fielding, 2008). The drafting of the action plan and the subsequent passage of the ordinance led to the 1998 establishment of an improved inspection program, now known as the Restaurant Hygiene Inspection Program (RHIP). The program is currently under the supervision of the Los Angeles County Department of Public Health.

Fig. 5. Standardized-format grade cards given to restaurants and other retail food establishments upon receiving an inspection score. Los Angeles County, California, USA, 2011.

On July 1, 2011, an addendum to the RHIP's policy and procedures manual was added to the program. This addendum provided guidance on inspection frequency requirements, outlining inspection frequencies for food facilities based on risk assessment results for the facility. Risk assessment designation or category is defined as "the categorization of a food facility based on the public health risk associated with the food products served, the methods of food preparation, and the operational history of the food facility" (Environmental Health Policy and Operations Manual, 2011). Currently, there are four risk assessment categories used to evaluate restaurants (Table 3).

Since implementation, the Restaurant Hygiene Inspection Program in Los Angeles County has been considered a relatively effective strategy for reducing the burden of foodborne disease in the region. Credited for improving hygiene standards among food facilities in the county, the program has been theorized by some to have helped reduce foodborne illness hospitalizations (Figure 6). In the year following implementation of the RHIP (1998), the grading program was associated with a 13.1 percent decrease (p<0.01) in the number of foodborne disease hospitalizations in Los Angeles County (Simon et al., 2005), albeit other factors may have also been attributed to this decrease, including random chance. Figure 6 shows the number of hospitalizations in the county, as compared to the rest of California (Simon et al., 2005).

Risk Category	Applies to, but not limited to:	Number of Inspections per year
High-Risk Category (Risk Assessment I)	-Meat Markets -Full service restaurants	3 inspections per year
Moderate-Risk Category (Risk Assessment II)	-Retail food stores with unpackaged foods -Fast food chains that sell chicken and beef -Quick service operations	2 inspections per year
Low-Risk Category (Risk Assessment III)	-Liquor stores -Food warehouses (retail & prepackaged) -Ice cream operations in drug stores -Operations that sell candy -Kitchen-less bars -Snack bars located in theatres	1 inspection per year* *If inspection score falls below 90, facility may be subject to additional inspections throughout the year.*
Temporary-Risk Category (Risk Assessment IV)	-Applies to facilities that have existing suspensions, violations, or investigations.	Establishments in this category will increase number of inspections by one (i.e., a restaurant in the low-risk category assigned to risk assessment IV will go from the typical 1 inspection per year to 2 inspections per year).

Table 3. The four risk assessment categories used to evaluate restaurants and other retail food establishments in Los Angeles County, California, USA.
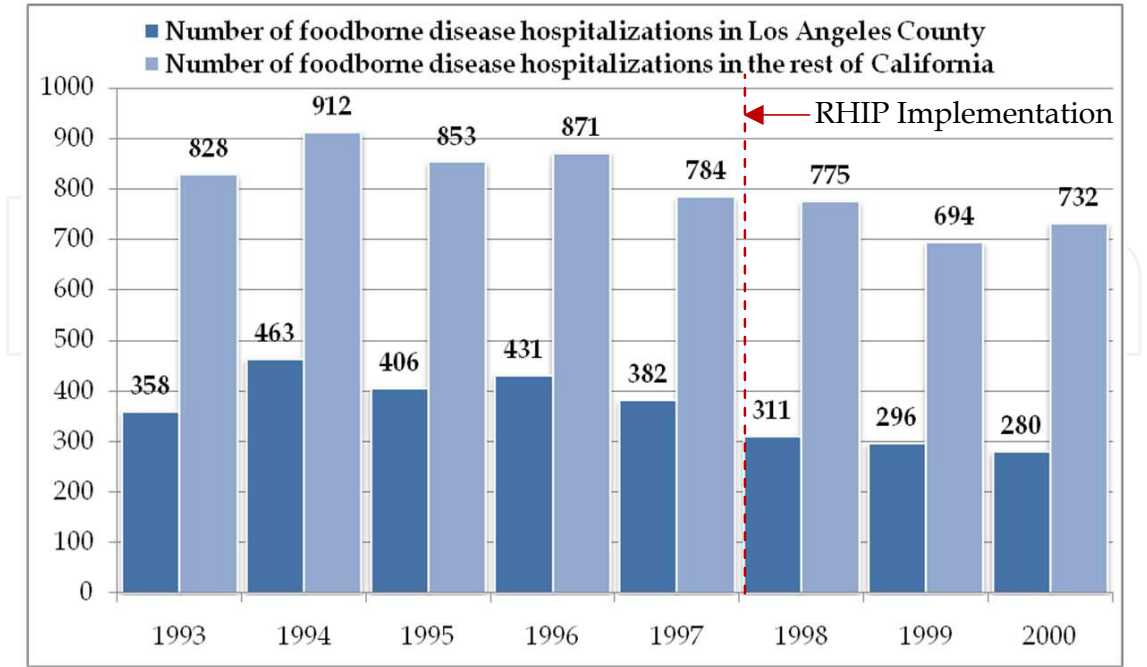

Fig. 6. Number of Foodborne-Disease Hospitalizations by Year, Los Angeles County and the Rest of California, 1993-2000, USA.

4.2.3 Home kitchens

Although restaurant inspections by local health departments routinely assess food-safety practices among food handlers in the retail food environment, similar scrutiny of home kitchens are rarely applied in most jurisdictions across the United States. In response to this potential risk in the home setting, the Los Angeles County Department of Public Health launched its Home Kitchen Self-Inspection Program in the spring of 2006 to promote safer food handling and preparation practices among the county's residents, using a voluntary self-inspection and education program. The program included the use of a web-based, self-assessment questionnaire, called the Food Safety Quiz (FSQ) that was based on emerging evidence indicating that online, interactive learning strategies are conducive to problem-based learning, improving self-efficacy and increasing self-mastery of selected skills (Kuo et al., 2010). The educational program stressed the importance of such preventive measures as hand washing before, during and after food preparation; refrigerating prepared foods in small containers; thoroughly cooking all foodstuffs derived from animal sources, particularly poultry, pork, egg products and meat dishes; avoiding recontamination within the kitchen after cooking is completed; and maintaining a sanitary kitchen and protecting prepared foods against rodent and insect contamination (Heymann, 2008; Scott, 2003).

During its initial program period from 2006-2008, more than 13,000 individuals participated in the program and completed the FSQ. Recent evaluation of program progress revealed that if home kitchens were graded similarly to restaurants in Los Angeles County, 61% would have received an **A** or **B** rating, as compared to 98% for the full-service restaurants based on rating criteria derived from the California Food Safety Code (Kuo et al., 2010). Among the program participants, approximately 27% reported not storing partially cooked food that was not used immediately in the refrigerator before final cooking; 26% reported that their kitchen shelves and cabinets were not clean and free from dust; and 36% said they did not have a properly working thermometer inside their refrigerators (Kuo et al., 2010).

The program evaluators concluded that even among interested and motivated persons who took the time to participate in the Home Kitchen Self-Inspection Program, food handling and preparation deficiencies were common in the home kitchen setting. This innovative, ongoing educational program in Los Angeles County underscores the importance of educating the public about home kitchen safety. Such programs, which emphasize feedback and interactive teaching about food safety, can complement the efforts of established restaurant hygiene rating programs to reduce foodborne illnesses in jurisdictions across the United States.

4.3 Exploring new strategies and technologies

New research on control measures is underway to investigate additional strategies for reducing foodborne illnesses, especially for *Salmonella* prevention. Advances in non-thermal technologies for microbial inactivation of *Salmonella*, such as the use of cold plasma, high pressure, and carbon dioxide are currently being evaluated (Bermúdez-Aguirre et al., 2011). Another approach that is currently being considered is the use of antimicrobial bottle coatings (i.e., packaging for liquid foods) to inactivate *Salmonella* in liquid egg albumen (Jin and Gurtler, 2011). Scientists are also actively exploring an experimental chlorate product that can be introduced into drinking water and feed for hens (McReynolds et al., 2005). Although promising, these innovations are not standalone interventions and are expected to augment existing control measures at various levels of the food distribution chain.

5. Conclusion

Salmonellosis caused by nontyphoid strains remains the most common foodborne illness reported in the United States. In spite of effective public health and regulatory efforts to control and prevent this infectious disease, the morbidity, mortality, and years of potential life lost due to this foodborne pathogen continue to be substantial. The overall incidence of laboratory confirmed *Salmonella* infection was 17.6 cases per 100,000 persons in 2010, which remains higher than the Healthy People 2020 objective of 11.4 cases per 100,000 persons (Figure 2). Active surveillance and continual efforts in developing and implementing control policies have helped federal and local health agencies in the United States make significant strides in combating this disease. Lessons learned from these efforts, including ways to work collaboratively across agencies at different levels of the food distribution chain have been invaluable for informing present and future *Salmonella* control policies and preventive measures in the United States. These lessons may have global implications for other jurisdictions abroad.

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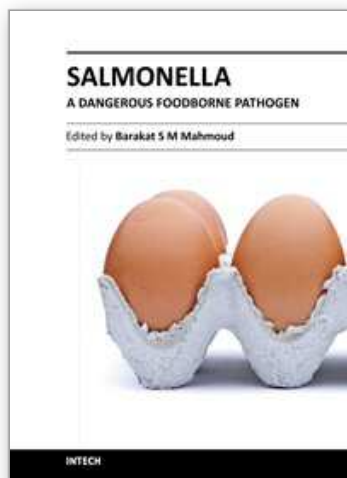
Salmonella - A Dangerous Foodborne Pathogen

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More than 2,500 serotypes of Salmonella exist. However, only some of these serotypes have been frequently associated with food-borne illnesses. Salmonella is the second most dominant bacterial cause of food-borne gastroenteritis worldwide. Often, most people who suffer from Salmonella infections have temporary gastroenteritis, which usually does not require treatment. However, when infection becomes invasive, antimicrobial treatment is mandatory. Symptoms generally occur 8 to 72 hours after ingestion of the pathogen and can last 3 to 5 days. Children, the elderly, and immunocompromised individuals are the most susceptible to salmonellosis infections. The annual economic cost due to food-borne Salmonella infections in the United States alone is estimated at $2.4 billion, with an estimated 1.4 million cases of salmonellosis and more than 500 deaths annually. This book contains nineteen chapters which cover a range of different topics, such as the role of foods in Salmonella infections, food-borne outbreaks caused by Salmonella, biofilm formation, antimicrobial drug resistance of Salmonella isolates, methods for controlling Salmonella in food, and Salmonella isolation and identification methods.

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