Epidemiology of Poultry Salmonellosis: A Review

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Abstract

Salmonellosis is one of the major foodborne disease of significant public health concern. Salmonellosis is considered as one of the most wide spread foodborne zoonosis in industrialized as well as developing countries. It is commonly found in the gastrointestinal tracts of animals and has been commonly associated with foods such as raw meat, poultry, eggs and dairy products. Poultry and poultry products derived from poultry are believed to make up fifty percent of the total vehicle of transmission of salmonella. Typhoid and non-typhoid salmonellosis remain major public health problems and are clearly the most economically important food borne disease. In many countries, the incidence of salmonellosis has markedly increased; however, paucity of good surveillance data exists. Salmonella has five different pathogenicity islands that encodes the majority of the virulence genes used for invasion and evasion of the host. The purpose of this review is to discuss the epidemiology, salmonella pathogenicity islands, invasion, molecular diagnosis, and global regional control and prevention strategies.

Keywords: Salmonellosis, poultry, public health, transmission.
Salmonella

Salmonella is a gram-negative rod shaped food borne pathogen responsible for causing severe gastroenteritis. Over 2400 different serotypes of Salmonella have been identified (Humphrey, 2000).

Salmonella is usually thought to be spread by the fecal-oral route. Salmonella is commonly found in the gastrointestinal tracts of animals, and has been commonly associated with foods such as raw meat, poultry, eggs, and dairy products.

Poultry and poultry products are believed to make up roughly 50% of the total vehicle of transmission when dealing with Salmonella (Texas Dept. of Health, 1998). The commercial poultry industry has a common turnover rate of forty two days in a broiler setting which can lead to a number of possible contamination sites such as litter, air, or feed (Humphrey, 2000). Birds are also raised in close proximity with other birds, which increases the likelihood of horizontal transfer.

It is believed that chickens have a chronic carrier state similar to that of Typhoid Mary. Typhoid Mary was a cook in New York City back in the 1900’s, who killed her employers by contaminating their food with Salmonella (Salyers and Whitt, 2002). The actual mechanism of this chronic carrier state is still unknown; however, if there is a large incidence of these carriers in the poultry industry, this could also be a large source of contamination.

Since Salmonella has several opportunities to be introduced to the host, there is an increased risk of Salmonella reaching the consumer. It is believed to be the source of between 2 and 4 million cases of food borne illness each year in the US with 600 of these cases resulting in death annually (Mead, 2000). The main symptoms of Salmonella consist of diarrhea, fever, nausea, vomiting, headache, and abdominal pain (CFSAN, 1996). The onset of these symptoms is usually between six to forty-eight hours after infection and usually lasts for one or two days depending on initial infective dose as well as strain type. The most susceptible human populations continue to be the young, old, and immunosuppressed. People who suffer from an autoimmune deficiency syndrome have been observed to exhibit a twenty-fold greater frequency of clinical salmonellosis than the rest of the general public (CFSAN, 1996).

Due to the number of food borne illness cases evolving from poultry and poultry products, it is important to understand how the bacteria are invading the product and ultimately causing illness in humans.

Epidemiology of Salmonellosis

The primary reservoir of salmonellae is in the intestinal tract of humans and animals, particularly in poultry and swine. As intestinal forms, the organisms are excreted in feces from which they may be transmitted by insects and other creatures to a large number of places such as water, soil and kitchen surfaces. Eggs, poultry and raw meat products are the most important food vehicles of Salmonella infection in human, with S. Typhimurium and S. Enteritidis being the most frequently isolated food borne serovars (Jay, 1992). Salmonella infection is usually acquired by the oral route, mainly by ingesting contaminated food or drink. Any food product is a potential source of human infection. Salmonella can be transmitted directly from human to human or from animal to human without the presence of contaminated food or water, but this is not a common mode of transmission. The true incidence of Salmonella infection is difficult to determine. Reported cases represent only a small proportion of actual number because it is only large outbreaks that are investigated and documented. Hence, sporadic cases are under reported because it is only patients with protracted diarrhea that take cases for microbiological evaluation (Hanes, 2003).

Infectious diseases spread through food or beverages are common, distressing, and sometimes life-threatening problem for millions of people around the world. The Center for disease Control and Prevention (CDC) estimates 76 million people suffer food borne illnesses each year in the United States, accounting for 325,000 hospitalizations and more than 5000 death. Food borne disease is extremely costly. Health experts estimates that the yearly cost of all food borne diseases in the United States is five to six billion dollars in direct medical expenses and lost productivity. Infections with Salmonella alone account for one billion dollars
yearly, in direct and indirect medical costs (NIAID Fact Sheet, 2005).

Salmonella is one of the microorganisms most frequently associated with foodborne outbreaks of illness. Meat products in general and poultry in particular are the most common sources of food poisoning by salmonella (D’Aoust, 1997; Antunes et al., 2003).

Salmonella Typhimurium DT104 is an emerging pathogen detected in several countries worldwide including the United States, the United Kingdom, Canada, Germany, France, Austria and Denmark. Illness has been associated with the consumption of pork sausages, chicken, unpasteurized dairy products, a brand of meat paste, and direct contact with ill animals (Hogue, 1997). Typhoid and non-typhoid salmonellosis remain major public health problems and are clearly the most economically important foodborne disease. The incidence of typhoid salmonellosis is stable, with very low numbers of cases in developed countries, but cases of non-typhoid salmonellosis are increasing worldwide. Non typhoid cases account for 1.3 billion cases of acute gastroenteritis/diarrhea with 3 million deaths and 16 million cases of typhoid fever with nearly 600,000 deaths (Pang et al., 1995). In the United States, the estimated annual incidence of salmonellosis in 1997 was 13.8 cases per 100,000 people. However, most cases are unreported, and the true incidence may be much higher. Although the incidence is greatest among children, outbreaks are common among individuals who are institutionalized and residents of nursing homes. Fewer cases of typhoid fever occur each year and these are increasingly associated with travel to developing countries (Zapor, 2005).

The Center for Disease Control and Prevention (CDC) in 1999 estimated that there were about 1.5 million cases with 500 deaths associated with the consumption of food contaminated with Salmonella (Schneider et al., 2003). In many countries, the incidence of salmonellosis has markedly increased; however, paucity of good surveillance data exists. In the Netherlands, which has a population of 15.8 million, 50,000 cases of salmonellosis are reported each year (Van Pelt and Valkenburgh, 2001). An estimated 12-33 million cases of typhoid fever occur globally each year, and the disease is endemic in many developing countries of the Indian subcontinent, South and Central America, and Africa (Zapor, 2005). An incidence in the frequency and severity of non-typhoidal strains has been reported in Patients with AIDS (Sperber and Schleupner, 1987). The most common species isolated are S. Typhimurium and S. Enteritidis (Levine et al., 1991) and infection often presents as recurrent diarrhea with bacteraemia which relapses frequency despite therapy.

Salmonelae can be transmitted vertically to the progeny of infected breeder flocks and horizontally within and between flocks (Gast, 1990). Vertical transmission of paratyphoid salmonellae to the progeny of infected breeder flocks can result from the production of eggs contaminated by salmonellae in the content or on the surface. During oviposition eggshells are often contaminated with paratyphoid salmonellae by fecal contamination. The penetration of salmonellae into and through the shell and shell membranes can result in direct transmission of infection to the developing embryo or can lead to exposure of the chick to infectious Salmonella organisms when the shell structure is disrupted during hatching. Horizontal transmission can occur by direct bird to bird contact, ingestion of contaminated feces or litter, contaminated water, personnel, farm and personal equipment, and a variety of other sources. Snoeyenbos et al., 1969 reported that, horizontal transmission could occur when unexposed day old chicks were raised together with infected day old chicks. Contaminated poultry house environments are identified as one of the major implication of paratyphoid salmonellae. Since the chicken itself is a reservoir of Salmonella, control measures need to start from the hatchery. Today, there are three different types of disease considered to be associated with Salmonella, which are caused by different strains: typhoid fever, gastroenteritis, and an invasive form. The two most widely known types are typhoid fever (caused by Salmonella Typhi) and the gastroenteritis form most often caused by Salmonella enteriditis Typhimurium or Salmonella enteriditis. However, S. Typhimurium has also been linked to typhoid like disease in mice (Kaufman et al., 2001). For the purposes of this review, the gastroenteritis form of disease caused by S.
Typhimurium will be used as the model to discuss the mechanisms of pathogenesis and the corresponding immune response.

In order to invade the host, Salmonella must undergo an infectious disease cycle. The conventional infectious cycle consists of: entry of the pathogen, establishment and multiplication, avoidance of host defenses, and finally damage and exit (Donneburg, 2000). Salmonella may undergo all of these steps when it invades the host. Due to the prevalence of Salmonella contamination on a number of different food products, it can easily gain access to and colonize the intestinal system of the host. Therefore, introduction to the host is not the problem for Salmonella. The problem lies in how it adapts to the condition of the gastrointestinal system via its virulence mechanisms located on the Salmonella pathogenicity islands.

**Salmonella Pathogenicity Islands**

Salmonella has five different pathogenicity islands that encode the majority of the virulence genes used for invasion and evasion in the host. Pathogenicity islands is a term used to describe a set of genes encoding for virulence that are located on a particular loci in the bacterial genome, but are absent from nonvirulent strains of the same species (Donneburg, 2000). Blanc-Potard and Groisman (1997), stated that “pathogenicity islands constitute a major driving force in the evolution of bacterial pathogens because their acquisition often determines the virulence properties of a microorganism.” The most often discussed group of genes involved in pathogenicity is Salmonella Pathogenicity Island 1 (SPI1), which is located at the 63 centisome (Wood et al., 1998). Salmonella Pathogenicity Island 1 is the most widely known island in that it encodes multiple genes required for Salmonella invasion and survival in the host system. It has been determined that more than 28 genes are responsible for encoding a type III secretion system (spa, inv, prg and org) secretory proteins (sip or ssp and spt) and regulatory mechanisms (invF and hilA), all of which aid in the ability of Salmonella to invade the host cell (Deiwick et al., 1998). Mutants with mutations in the sip gene have been shown to decrease the amount of fluid buildup in the ileum which shows that the expression of this gene is required to induce diarrhea (Zhang et al., 2003). hilA (Hyper Invasive Locus) is a transcriptional activator encoded on SPI1 (Bajaj, et al., 1995). The hilA encoding protein was believed to be roughly 531 to 553 amino acids in length (Bajaj et al., 1995). It was later proven by Rodriguez and co-workers (2002) that the hilA gene encodes for a protein that is 553 amino acids (63kDa) in length. hilA is also thought to be a requirement for Salmonella invasion due to its transcriptional properties (Bajaj et al., 1995). hilA has also been shown to trigger the rendering of lacZY infusion genes where it is in a gene fusion (Bajaj et al., 1996). This allows for experiments to be conducted that look into what environmental stimuli cause the induction of hilA in Salmonella in order to determine the virulence response upon induction. SPI1 also encodes one of the two type III secretion systems of Salmonella. The type III secretion system encoded on SPI1 is a key component in piercing through the epithelial layer of the intestine and delivering proteins needed for virulence mechanisms (Deiwick et al., 1998). The second Salmonella Pathogenicity Island (SPI2) is located at the 30 centisome (Wood et al., 1998). SPI2 encodes the components of the second. Type III secretion system of Salmonella (Wood et al., 1998). This secretion system is more homogenous to the secretion system of Enteropathogenic Escherichia coli (EPEC) than to the secretion system encoded on SPI (Sukhan, 2000). The type III secretion system encoded on SPI2 allows Salmonella to reproduce in the spleen upon infection of the host system (Deiwick et al., 1998). SPI2 has also been shown to be required for the expansion of systemic infection (Shea et al., 1996). It was discovered that SPI2 also has genes for a two component regulatory system (Ochman et al., 1996; Shea et al., 1996; Diewick et al., 1998). SPI2 genes have additionally been shown to be expressed only when entry into the mammalian cell has occurred (Cirillo et al., 1998). Researchers are beginning to understand the role of the last three Salmonella pathogenicity islands in the ability of Salmonella to cause infection and circumvent the immune response of the host. Salmonella Pathogenicity Island 3 (SPI3) is located at the 82 centisome (Wood et al., 1998). SPI3 encodes genes essential...
for the survival of Salmonella in macrophages namely mtgC and mtgB (Blanc-Potard and Groisman, 1997). Salmonella Pathogenicity Island 4 (SPI4) is located at the 92 centisome (Wong et al., 1998). This Pathogenicity Island is flanked by ssb on one side and soxSR on the other. SPI4 is believed to encode genes involved in toxin secretion and perhaps even a type I secretion system, due to the homology between the open reading frames (ORFs) of SPI4 when compared to known proteins involved in toxin secretion (Wong et al., 1998). A type I secretion system is used to form a pore between both inner and outer membranes to transport proteins across to the host (Salyers and Whitt, 2002). SPI4 also was the first pathogenicity island to be completely sequenced owing to its short length, roughly 25kb (Wong et al., 1998). Salmonella Pathogenicity Island 5 is located at roughly the 20 centisome (Wood et al., 1998). SPI5 has been discovered to contain four pathogenicity island- encoded proteins, as well as sopB and orfX, which are believed to be linked to enteropathogenicity (Wood et al., 1998). One of these proteins, sopB, has been shown to instigate cellular responses, causing an influx of polymorphonuclear leukocytes (PMNs), thereby establishing fluid secretion in the intestinal epithelium (Wood et al., 1998).

**Invasion**

Salmonella also has genes that encode for a number of different virulence factors such as fimbriae, acid survival, and iron acquisition systems, but these genes are not as well understood as the genes encoded for on the pathogenicity islands. All of these genes and pathogenicity islands which encode them are key to the survival of Salmonella within the host its ability to colonize and invade; thereby ultimately leading to infection. The specifics of how these characteristics of Salmonella help to accomplish the infection will be discussed further along with the systematic route to infection of the host. The clinical beginning to a Salmonella infection lies in the initial contact of Salmonella with the epithelium of the gastrointestinal system of the particular host such as humans or chickens. The bacteria that have survived long enough for attachment and penetration of the epithelium had to overcome such hazards such as low pH in the gastrointestinal system as well as any antimicrobial and/or physical barriers. It is believed that the appendages such as fimbriae, seen only when in contact with the epithelial cells help mediate this survival (Ginochio et al., 1994). These structures are no longer observed upon bacterial entry into the cell. The next challenge facing the invading bacteria involves the colonization of the intestine through attachment (Lucas and Lee, 2000). Salmonella cells must also be able to undergo proliferation as well as evade any further barriers, such as pH or acid shock that may try to hamper their colonization (Lucas and Lee, 2000). The preferred port of entry for Salmonella is the Peyer’s patches in the distal ileum (Jones, 1997). Intestinal antigens are sampled by the Peyer’s patches, which are made up of specialized lymphoid (Slauch et al., 1997). Peyer’s patches are made up of twenty-eight percent T cells with a CD4: CD8 ratio of 3.7:1 (Hathaway and Kraehenbuhl, 2000). M cells form a cover over the Peyer’s patches. M cells are responsible for the consumption of antigens found in the lumen (Hathaway and Kraehenbuhl, 2000; Slauch et al., 1997) and M cells are believed to be the route of invasion for Salmonella (Clark et al., 1998; Slauch et al., 1997). The invasion of M cells is also associated with their destruction as well as the destruction of follicle associated epithelium (Slauch et al., 1997). When M cells take up the antigen, they send it to the immune system cells (Hathaway and Kraehenbuhl, 2000). After passage through the Peyer’s patch, Salmonella enters the follicle dome, which is home to the host lymphocytes and macrophages (Jones and Falkow, 1996). Antigen presenting cells seize the antigen, which upon processing; will be taken to the T cells. This process initiates the production of IgA specific B cells (Hathaway and Kraehenbuhl, 2000). The B and T cells are relocated to the lymph nodes (lymph “accumulations” in birds) and ultimately the blood system. This is the process by which the common mucosal immune system (CMIS) is initiated (Hathaway and Kraehenbuhl, 2000). This allows IgA to be released at mucosal effector sites (Hathaway and Kraehenbuhl, 2000). Dendritic cells (DCs) have recently been associated with non-invasive Salmonella movement without M cells.
The ability to deliver the secreted proteins to the cytosol of host cells (Sukhan, 2000).

The type III secretion system is a needed commodity in order for the Salmonella bacteria to be taken up within the host cell. Once the Salmonella have been taken up into the cell, they rely on other mechanisms for survival. In the cell, Salmonella has evolved ways to work around the targeting of these internal bacteria to the phagosome-lysosome fusion pathway. S. Typhimurium has been shown to need an acidic pH in order to induce reproduction and survival within the cells (Rathman et al., 1996). It is believed to take up residence in the membrane bound vacuole of phagocytic and non-phagocytic cells (Finlay and Falkow, 1997). When Salmonella enters the vacuole, the presence of lysosomal glycoproteins and removal of the surface marker assists with changes to the vacuole (Finlay and Falkow, 1997). The type III secretion system causes subsequent neutrophil (heterophil in birds) and fluid accretion in the ileum (Zhang et al., 2003). The neutrophil addition causes necrosis of the surrounding tissue and ultimately diarrhea thereby bringing about the symptoms of disease (Zhang et al., 2003).

**Molecular Diagnosis**

**Polymerase Chain Reaction (PCR)**

This assay is based on the ability of Salmonella specific primers, through complementary DNA base pairing, to anneal only to the target sequence. Thermostable DNA polymerase (Taqpolymerase) recognizes the template primer complex as a substrate, which results in the simultaneous copying of both strands of the segment of DNA between the two annealed primers. The denaturation, annealing and elongation steps take place in a cyclical fashion, relying on the thermostability of the Taq polymerase, until the target sequence is amplified to detectable amounts (van der Zee and Huis, 2000). Before starting the first cycle in the thermocycler the DNA, primers, the polymerase, deoxynucleotide triphosphates (dNTPs), and a buffer are mixed in a reaction tube. The targeted region of the Salmonella genome is amplified by repetition of a three-step process: (a) Denaturation of the double-stranded DNA into single strands by heating (b) annealing
specific, complementary, oligonucleotide primers to the single stranded DNA by cooling and (c) enzymatically extending the primers to produce an exact copy of the original double-stranded target sequence. This process from (a) to (c) is usually repeated in 30 to 40 cycles. In the final step the detection of the amplified target DNA is done using agarose gel electrophoresis. Before PCR it is often necessary to first grow the bacteria on an enrichment medium and then extract and purify the DNA (Hernandez et al., 1995). Zhang and Weiner (2000) reported a method of bacterial DNA extraction from liquid media by using the cetyltrimethylammonium bromide (CTAB). PCR-based assays are the latest technique for the detection of pathogens including Salmonella in food samples (Uyttendaele et al., 2003; Nakano et al., 2003).

Food borne illness is an ever-increasing concern among the consumers about the food supply. Surveillance of the Salmonella outbreaks was activated in 1962 by the Council of State and Territorial Epidemiologists, the Association of Public Health Laboratories, and the Centers for Disease Control and Prevention (CDC). The main objectives in starting this investigation were to define endemic patterns of salmonellosis, to identify trends in disease transmission, to detect outbreaks, and to monitor control efforts (Olsen et al., 2001). There was a 9.6% increase in laboratory confirmed bacterial infective diarrheal cases in 1997 when compared to 1996 (FoodNet, 1998). However, since 1997 there has been a nineteen percent decline in bacterial food borne infections (Kennedy et al., 2000). Salmonella cases however increased in 1999 and were accompanied by decreases in Campylobacter jejuni, Shigella, and E. coli O157:H7 (Kennedy, et al., 2000). Cases of illness where a food source was identified as the vehicle for infection have increased. It is believed that food borne diseases cause roughly 76 million illnesses, 325,000 hospitalizations, and 5,000 deaths each year in the United States alone (Kennedy et al., 2000; CDC 2001). Salmonella is the second most often isolated bacteria associated with food at roughly 27.4% of all food borne infections (FoodNet, 1998). The Salmonella surveillance system has shown that from 1987 to 1997 44,863 isolates were imparted to the CDC (Olsen et al., 2001) (Table 1) Salmonella infections may not be limited to the digestive tract and can lead to septic arthritis due to localized infection, or sepsis. The most susceptible populations continue to be the young, old, and immunosuppressed. Estimates of medical costs and lost productivity due to foodborne Salmonella infections range from $464 million to $2.329 billion (Frenzen 1999). In 1999, twenty two percent of all culture confirmed Salmonella individuals were hospitalized (Kennedy et al., 2000). Very low infectious doses are often associated with high fat foods (Portillo, 2000). Salmonella has shown a higher heat resistance in foods with a high fat content. The infectious dose for humans may be as low as 1-10 Salmonella cells, though typically a dose of 104 to 106 Salmonella cells is necessary. Salmonella has also been commonly associated with foods such as raw meat, poultry, eggs, and dairy products.

Table 1: Annual number of reported Salmonella isolates from humans and their ranking in the United States, 1987–1997. (Adapted from Olsen et al., 2001).

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<tr>
<td>Typhimurium</td>
<td>7950</td>
<td>8743</td>
<td>8365</td>
<td>9702</td>
<td>9,501</td>
<td>9,116</td>
<td>53,377</td>
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<td>Enteritidis</td>
<td>6578</td>
<td>8071</td>
<td>9866</td>
<td>10,200</td>
<td>9,570</td>
<td>7,924</td>
<td>52,209</td>
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<td>Heidelberg</td>
<td>2528</td>
<td>2457</td>
<td>1825</td>
<td>2095</td>
<td>1,998</td>
<td>2,104</td>
<td>13,007</td>
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<tr>
<td>Newport</td>
<td>1481</td>
<td>1487</td>
<td>1673</td>
<td>2566</td>
<td>1,985</td>
<td>1,584</td>
<td>10,776</td>
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<td>750</td>
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<td>752</td>
<td>683</td>
<td>605</td>
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<td>4,180</td>
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<td>Montevideo</td>
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<td>631</td>
<td>685</td>
<td>1,227</td>
<td>718</td>
<td>4,609</td>
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<td>549</td>
<td>625</td>
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<td>Aviana</td>
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<td>641</td>
<td>540</td>
<td>758</td>
<td>749</td>
<td>675</td>
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<td>Hadar</td>
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<td>62</td>
<td>595</td>
<td>690</td>
<td>623</td>
<td>3,089</td>
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**Global Regional Control and Prevention Strategies**

Salmonella can be effectively controlled by coordinated and simultaneous interventions on the problem from different directions. At the farm level, eggs and chicks or poults can only be obtained from salmonella-free breeding flocks. Hatching eggs should be properly disinfected and hatched from farms adhering to stringent sanitation standards. Poultry houses should be thoroughly cleaned and disinfected. Rodents and insect control measures should be incorporated into house design and management and verified by periodic testing. Rigidly enforced biosecurity practices should be implemented, restricting entry onto poultry housing premises to only authorized personnel and equipment, preventing horizontal transmission of salmonellae between houses. Only pelleted feed containing no animal protein should be used, to minimize contamination. Treatments such as medication, competitive exclusion cultures, or vaccination can be applied to reduce Salmonella susceptibility. Frequent testing of poultry and environmental samples has also reportedly been successful for salmonella control in the poultry industry. Such coordinated control programs have reportedly been successful in addressing Salmonella problems in both chickens and turkeys. At the processing stage, implementation of a Hazard Analysis and Critical Control Points (HACCP) Plan has been effective in reducing Salmonella contamination of carcasses. The United States Department of Agriculture (USDA), Food Safety Inspection Services (FSIS) conducts annual surveillance of microbial contamination in processing plants and slaughter houses to monitor microbial contamination of carcasses. State or country department of Health loosely regulate transportation and retail distribution of processed chicken products. Effective development and implementation of HACCP and surveillance programs to monitor microbial contaminations at the retail store level are needed to close that final gap in the Salmonella control spectrum before the product reaches the consumer. Other measures, such as gas treated packaging, irradiation, organic acid treatment and biofilm treatments have proved to effectively lower or inhibit Salmonella and other microbial growth product. Continuous real-time public health surveillance for food-borne infections is critical to improve prevention. Surveillance can allow comparison with historical data helping to characterize trends in occurrences of microbes and identify the outbreaks at an early stage (Mahon et al., 1997; Lyytikäinen et al., 2000a). Surveillance data also provides information about the food items carrying a high risk of transmitting food-borne pathogens. With this information, patient education can be carried out through published recommendations. Furthermore, industrial hygiene by optimal preparation of food items, elimination of the organism from food and more frequent screening for the microbes is necessary.

**Conclusion**

Poultry houses should be thoroughly cleaned and disinfected. Rodents and insect control measures should be incorporated into the poultry house design. Rigidly enforced biosecurity practices should be implemented, restricting entry onto poultry housing premises to only authorized personnel and equipment, preventing horizontal transmission of salmonellae between houses. Treatments such as medication, competitive exclusion cultures, or vaccination can be applied to reduce Salmonella susceptibility.

**References**


