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Epidemiology of Foodborne Illness

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1. Introduction

Foodborne illnesses comprise a broad spectrum of diseases and are responsible for substantial morbidity and mortality worldwide. It is a growing public health problem in developing as well as developed countries. It is difficult to determine the exact mortality associated with foodborne illnesses (Helms et al., 2003). However, worldwide an estimated 2 million deaths occurred due to gastrointestinal illness, during the year 2005 (Fleury et al., 2008). More than 250 different foodborne illnesses are caused by various pathogens or by toxins (Linscott, 2011). Foodborne illnesses result from consumption of food containing pathogens such as bacteria, viruses, parasites or the food contaminated by poisonous chemicals or bio-toxins (World Health Organization [WHO], 2011c). Although majority of the foodborne illness cases are mild and self-limiting, severe cases can occur in high risk groups resulting in high mortality and morbidity in this group. The high risk groups for foodborne diseases include infants, young children, the elderly and the immunocompromised persons (Fleury et al., 2008).
There are changes in the spectrum of foodborne illnesses along with demographic and epidemiologic changes in the population. A century ago, cholera and typhoid fever were prevalent foodborne illnesses, globally. During last few decades, other foodborne infections have emerged, such as diarrheal illness caused by the parasite *Cyclospora*, and the bacterium *Vibrio parahemolyticus*. The newly identified microbes pose a threat to public health as they can easily spread globally and can mutate to form new pathogens. In the United States, 31 different pathogens are known to cause foodborne illness, however, numerous episodes of foodborne illnesses and hospitalizations are caused by unspecified agents (Centers for Disease Control and Prevention [CDC], 2011a).
Although foodborne illnesses cause substantial morbidity in the developed countries, the main burden is borne by developing countries. These illnesses are an obstacle to global development efforts and in the achievement of the Millennium Development Goals (MDGs) (WHO, 2011c). There is an impact of foodborne illnesses on four out of the eight MDGs. These include MDG 1(Eradication of extreme poverty); MDG 3 (Reduction in child mortality); MDG 5 (Improvement of maternal health); MDG 6 (Combating HIV/AIDS and other illnesses). The population in developing countries is more prone to suffer from foodborne illnesses because of multiple reasons, including lack of access to clean water for food preparation; inappropriate transportation and storage of foods; and lack of awareness regarding safe and hygienic food practices (WHO, 2011c). Moreover, majority of the

developing countries have limited capacity to implement rules and regulations regarding food safety. Also, there is lack of effective surveillance and monitoring systems for foodborne illness, inspection systems for food safety, and educational programs regarding awareness of food hygiene (WHO, 2011a).

Foodborne illnesses have an impact on the public health as well as economy of a country (Helms et al., 2003). They have a negative impact on the trade and industries of the affected countries. Identification of a contaminated food product can result in recalling of that specific food product leading to economic loss to the industry. Foodborne outbreaks may lead to closure of the food outlets or food industry resulting in job losses for workers, affecting the individuals as well as the communities. Moreover, local foodborne illness outbreaks may become a global threat. The health of people in many countries can be affected by consuming contaminated food products, and may negatively impact a country's tourist industry. The foodborne illness outbreaks are reported frequently at national as well as international level underscoring the importance of food safety(WHO, 2011c).

Increasing commercialization of food production has resulted in the emergence and dissemination of previously unknown pathogens, and resulted in diseases such as bovine spongiform encephalopathy (BSE). BSE is a variant of Creutzfeldt-Jakob disease (vCJD) which affected human population in UK during the 1990s (WHO, 2011c).

During last few decades there are advances in technology, regulation, and awareness regarding food safety but new challenges have emerged because of mass production, distribution, and importation of food and emerging foodborne pathogens (Scallan, 2007; Taormina & Beuchat, 1999). One of the major issues of public health importance is the increasing resistance of foodborne pathogens to antibiotics (WHO, 2011c).

For the sake of public health, it is important to understand the epidemiology of foodborne illnesses because it will help in prevention and control efforts, appropriately allocating resources to control foodborne illness, monitoring and evaluation of food safety measures, development of new food safety standards, and assessment of the cost-effectiveness of interventions. The purpose of this chapter is to describe the epidemiology of foodborne illness in order to determine the magnitude of the problem, risk factors, monitoring and surveillance and measures of control.

2. Impact of foodborne illness

2.1 Public health impact

Foodborne illnesses are prevalent (Hoffman et al., 2005) but the magnitude of illness and associated deaths are not accurately reflected by the data available in both developed and developing countries. To fill the current data gap, the World Health Organization (WHO) has taken initiative for estimation of the global burden of foodborne illnesses (Kuchenmüller et al., 2009). World Health Organization and the US Centers for Disease Control and Prevention (CDC) report every year a large number of people affected by foodborne illnesses (Busani, Scavia, Luzzi, & Caprioli, 2006). Globally, an estimated 2 million people died from diarrheal diseases in 2005; approximately 70% of diarrheal diseases are foodborne. It is estimated that up to 30% of the population suffer from foodborne illnesses each year in some industrialized countries (WHO, 2011c). According to the estimation by CDC in 1999, around 76 million foodborne illnesses occur annually, resulting in 325,000 hospitalizations and 5200 deaths in the United States (Buzby & Roberts, 2009). However, a decrease in the incidence rates of notified foodborne illness was noticed from 1996 to 2005, but these rates have remained static since 2005 (Anderson, Verrill, & Sahyoun, 2011). There is a 20% reduction in illnesses caused by the specific pathogens tracked by FoodNet system, over the past 10 years. There are many explanations for this decrease in foodborne illness. It may be due to improved food safety because of regulatory and industry efforts or because of better detection, prevention, education, and control efforts (CDC, 2011a). According to 2011 estimates of CDC, annually 48 million Americans get sick, there are 128,000 hospitalizations, and 3,000 deaths due to foodborne illnesses in the US (CDC, 2011b). In Canada, an estimated 1.3 episodes per person-year of enteric disease occur (Fleury et al., 2008). In New Zealand, there are an estimated 119,320 episodes of foodborne illnesses each year, accounting for a rate of 3,241 per 100,000 population (Scott et al., 2000).

Foodborne-illness outbreaks are under-reported and it is estimated that 68% of foodborne-illness outbreaks are notified to the Centers for Disease Control and Prevention (Jones et al., 2004). Even during foodborne illness outbreaks, only a small proportion of the total number of cases is reported. In the United States, during 1993–1997, an average of 550 foodborne illness outbreaks was reported annually. Each outbreak had an average of 31 cases (Jones et al., 2004).

Foodborne illnesses also play an important role in new and emerging infections. It is estimated that during past 60 years, an estimated 30% of all emerging infections comprised of pathogens transmitted through food leading to foodborne illness (Kuchenmüller et al., 2009).

2.2 Economic impact of foodborne illness

Every illness has an economic cost and same is the case with foodborne illness. However, the economic cost of health losses related to foodborne illnesses has not been extensively studied. There are few studies available which provide either incomplete cost estimates or their estimates are based on limiting assumptions (Buzby & Roberts, 2009). In the United States, data from Foodborne Diseases Active Surveillance Network (FoodNet) and other related studies contributed to estimates of the economic cost of foodborne illness (Angulo & Scallan, 2007).

The annual economic cost of foodborne illness is calculated by multiplying the cost per case with the expected annual number of foodborne illnesses experienced. It was estimated that in 1999, the US government spent $1 billion on food safety efforts at federal level, an additional $300 million were spent by state governments. Moreover, it is estimated that a total of $152 billion a year is spent on foodborne illness in the U.S. (Scharff, 2010). The foodborne illness also bears substantial economic burden at regional level. The annual estimated economic cost of foodborne illness for Ohio is between $1.0 and $7.1 billion i-e., cost of $91 to $624 per Ohio resident (Scharff, McDowell, & Medeiros, 2009).

A retrospective study performed in Uppsala, Sweden during 1998–99, estimated average costs per foodborne illness as $246 to society and $57 to the patient. An estimated $123 million was the annual cost of foodborne illnesses in Sweden (Lindqvist et al., 2001).

In New Zealand, the total cost of foodborne illness cases was estimated to be $55.1 million, accounting for $462 per case. The direct medical costs were calculated as $2.1 million while direct non-medical costs were $0.2 million (Scott et al., 2000). The estimated total costs were $161.9 million including government outlays of $16.4 million, industry costs of $12.3 million and $133.2 million for incident case costs of disease associated with treatment, loss of output and residual lifestyle loss (New Zealand Food Safety Authority, 2010).

2.3 The unknown burden

Data from surveillance systems and sentinel sites show only the tip of the iceberg and do not reflect true disease burden of foodborne illness (Figure 1). The reasons are that the sick persons may not seek medical care, may not be tested at laboratory or may not be notified to the relevant health authorities (WHO, 2011b).

Fig. 1. The Unknown burden of foodborne illness. Adapted from WHO. Available at: http://www.who.int/foodsafety/foodborne_disease/ferg/en/index1.html Accessed August 04, 2011.

3. Risk factors

Factors such as socioeconomic status, malnutrition, micronutrient deficiencies, genetic factors and immunity play an important role in the causation of foodborne illnesses. The risk factors may be related to the host as well as to the environment.

3.1 Host risk factors

The risk factors for the foodborne illness caused by common pathogens have been determined by various studies. A case-control study conducted in the United States determined risk factors for Campylobacter infection. Traveling abroad and consumption of chicken or non-poultry meat prepared at a restaurant were stated as the main risk factors (Friedman et al., 2004). In Australia, annually an estimated 50,500 cases of *Campylobacter* infection in persons more than 5 years of age are associated with consumption of chicken (Stafford et al., 2008).

The risk factors for *Salmonella* Enteritidis have been explored in various studies conducted in different regions of the world. Foodborne Diseases Active Surveillance Network (FoodNet) in US, conducted a population-based case-control study for 12-month period during 2002–2003, to determine the risk factors associated with sporadic *Salmonella* Enteritidis infection. The study enrolled 218 cases and 742 controls. Travelling outside US five days before the onset of illness was found to be strongly associated with *Salmonella* Enteritidis infection [odds ratio (OR) 53, 95% Confidence Interval (CI) 23–125]. In addition, eating chicken cooked outside the home, consuming undercooked eggs and contact with birds and reptiles were associated with *Salmonella* Enteritidis infections (Marcus et al., 2007). In Denmark, a prospective case-control study of sporadic *Salmonella* Enteritidis infection was conducted in 1997–1999. It was revealed that foreign travel had a positive association with the disease. Foreign travelers were approximately three times more likely to suffer from *Salmonella* Enteritidis infection as compared to the non-travelers. Among non-travelers, the risk factors were eating eggs or dishes containing raw or undercooked eggs. The study concluded that eggs are the main source of *Salmonella* Enteritidis in Denmark (Mølbak & Neimann, 2002). A case-control study to determine risk factors for salmonellosis was conducted in the Netherlands. Consumption of raw eggs (OR 3.1, 95% CI 1.3–7.4) and products containing raw eggs (OR 1.8, 95% CI 1.1–3.0) were found to be the risk factors associated with *Salmonella* Enteritidis infection. The risk factors for *Salmonella* Typhimurium infection included contact with raw meat (OR 3.0, 95% CI 1.1–7.9), consumption of undercooked meat (OR 2.2, 95% CI 1.1–4.1) and recent antibiotic use (OR 1.9, 95% CI 1.0–3.4) (Doorduyn, Van Den Brandhof, Van Duynhoven, Wannet, & Van Pelt, 2006). In Canada, a matched case-control study was conducted to determine risk factors for sporadic *Salmonella* Typhimurium infection. The study was conducted during 1999 and 2000. *Salmonella* Typhimurium phage-type 104 (DT104) and non-DT104 diarrheal illness in Canada, were studied. The risk factors associated with DT104 illness were recent antibiotic use (OR 5.2, 95% CI 1.8–15.3), residence on a livestock farm (OR 4.9, 95% CI 1.9–18.9), and travel outside Canada in the recent past (OR 4.1, 95% CI 1.2–13.8) (Doré et al., 2004). To determine the risk factors for typhoid fever, a community-based case-control study was conducted during 2001- 2003, in Jakarta, Indonesia. The risk factors for typhoid fever were recent typhoid fever in the household (OR 2.38, 95% CI 1.03-5.48); not using soap for hand washing (OR 1.91, 95% CI 1.06-3.46); eating and sharing food in the same dish (OR 1.93, 95% CI 1.10-3.37), and non availability of appropriate sanitation services (OR 2.20, 95% CI 1.06-4.55). Typhoid fever was also found to be associated with young age and female gender (Vollaard et al., 2004).

There is a well-established association between *E. coli* O157:H7 infections and consumption of contaminated ground beef. Sporadic *E. coli* O157:H7 infection has been found to be linked to eating undercooked hamburgers and exposure to cattle on farms (Allos, Moore, Griffin, & Tauxe, 2004). A case-control study of sporadic Shiga toxin-producing *Escherichia coli* O157 (STEC O157) infections was conducted in 1999–2000, in US. In this 12-month study, 283 patients and 534 controls participated. The risk factors for STEC O157 infection included consumption of pink hamburgers, intake of unsafe surface water, and exposure to cattle (Voetsch et al., 2007).

3.2 Environmental risk factors

The environmental risk factors, food industry, food manufacturing, retail and catering sectors play important role in foodborne illness. Various studies of both sporadic and outbreak-associated illness involving different geographic areas, varied study designs, and a variety of pathogens have revealed that restaurants play an important role as source of foodborne illness in the US. Many factors may contribute to an increased risk of foodborne illness due to foods consumed in restaurants such as cross-contamination events within restaurants (Jones & Angulo, 2006). Research has shown that populations with low socioeconomic status have less access to high-quality food products, resulting in reliance on small markets that may sell foods of poorer quality. These populations have less access to supermarkets selling a variety of fresh fruits and vegetables and low-fat foods. Consumption of a poorer- quality diet along with other risk factors may lead to foodborne illness.

4. Causative agents

A variety of agents can cause foodborne illnesses. Although most of the foodborne illnesses are caused by bacterial or viral pathogens, there are certain non-infectious causes such as, chemicals and toxins. Approximately 67% of all foodborne illnesses caused by pathogens have viral etiology. Most commonly implicated viruses in foodborne illnesses are norovirus, hepatitis A virus, hepatitis E virus, rotavirus, and astrovirus (Atreya, 2004).

4.1 Foodborne pathogens

Various bacterial, viral and parasitic agents causing foodborne illness of public health importance are listed below (Nelson & Williams, 2007; The Food Safety and Inspection Service [FSIS], 2008):

Bacterial Agents

- *Listeria monocytogenes*
- *Staphylococcus aureus*
- *Bacillus cereus*
- *Bacillus anthracis*
- *Clostridium botulinum*
- *Clostridium perfringens*
- *Clostridium difficile*
- *Salmonella* spp
- *Shigella* spp
- *Campylobacter* spp
- *Escherichia coli* 0157:H7
- *Yersinia enterocolitica*
- *Brucella* spp
- *Vibrio Cholerae*

Viral Agents

- *Norovirus*
- *Hepatitis A*
- *Hepatitis E*
- *Adenovirus (Enteric)*
- *Rotaviruses*

Parasitic Agents

- *Cryptosporidium sp.*
- *Cyclospora cayetanensis*
- *Giardia lamblia*
- *Entamoeba histolytica*
- *Balantadium coli*

5. Clinical manifestations

The clinical features of foodborne illness include nausea, vomiting, diarrhea, abdominal pain and fever (McCulloch, 2000). Symptoms of foodborne illnesses may persist for two to three days. In majority of patients, the illness is mild in nature; however, severe complications may occur in some cases. The serious complications of foodborne illness include hypovolemic shock, septicemia, hemolytic uremic syndrome, reactive arthritis, and

Guillan- Barré syndrome. Severe complications may occur in immunocompromised cases, patients with co-morbidities, and in very young or elderly patients. Several cases of foodborne illnesses remain undiagnosed as the patient may not seek medical attention. If a person reports to a health care facility, generally, stool specimens are taken and tested for bacteria and parasites (Linscott, 2011).

Table 1 displays the common causative agents of foodborne illnesses along with their incubation period, clinical features, possible contaminants, diagnostic procedures and steps for prevention (Iowa State University, 2010; Linscott, 2011; Nelson & Williams, 2007).

Organism	**Incubation Period**	**Clinical Features**	**Possible contaminants**	**Laboratory diagnosis**	**Preventive measures**
Bacillus cereus	30 minutes to 15 hours	Sudden onset of nausea and vomiting, abdominal cramps with or without diarrhea	Cooked but not properly refrigerated foods, such as vegetables, fish, rice, potatoes and pasta.	Stool test Food sources may be tested.	Careful attention to food preparation, cooking and storage standards
Brucella sp.	7 to 21 days	Fever, night sweats, backache, muscle aches, diarrhea	Unpasteurized dairy foods and meat	Serology, blood culture.	Consumption of pasteurized dairy products. Cooking meat thoroughly
Campylobacter jejuni	1 to 7 days	Fever, headache, nausea, abdominal cramps, diarrhea. Guillian-Barre syndrome may occur in some patients.	Raw and undercooked poultry, eggs, raw beef, unpasteurized milk, contaminated water	Stool culture, rapid immune-chromogenic tests, molecular assays.	Pasteurization of milk, cooking foods properly, prevention of cross-contamination
Clostridium botulinum – preformed toxin	12 to 72 hours	Abdominal cramps, nausea, vomiting, diarrhea, diplopia, blurred vision, headache, dryness of mouth, muscle paralysis, respiratory failure, nerve damage.	Inappropriately canned foods, meats, sausage, fish.	Detection of botulinum toxin in serum, stool, or patient's food	Proper canning of foods, proper cooking of foods
Clostridium perfringen-toxin	8 to 22 hours	Nausea, abdominal cramps and diarrhea, dehydration in some cases	Meat, poultry, gravy, inadequately reheated food	Stool test for enterotoxin	Maintenance of proper cooking temperatures

Organism	Incubation Period	Clinical Features	Possible contaminants	Laboratory diagnosis	Preventive measures
Cryptosporidium sp.	2 to 10 days	Nausea, loss of appetite, watery diarrhea accompanied by mild abdominal cramp; severity depends on host immune status.	Undercooked food or food contaminated by ill food handler, contaminated drinking water or milk	Stool test for detecting oocysts by modified acid- fast stain, direct fluorescent antibodies, or with immunoassays	Avoidance of contaminated water or food, washing hands after using the toilet and before handling food.
Cyclospora cayetanensis	1 to 14 days	Watery diarrhea, abdominal cramps, nausea, anorexia, and weight loss	Fresh fruits and vegetables	Stool test for detecting oocysts by modified acid- fast stain	Hygienic practices in the agricultural setting and in the individual's environment.
Entero-hemorrhagic E.coli – 0157;H7 and other Shiga toxins	1 to 8 days	Bloody diarrhea, vomiting, abdominal cramps, fever, hemorrhagic colitis, hemolytic uremic syndrome	Undercooked ground beef, unpasteurized milk, fruit juices, raw fruits, and vegetables	Stool culture for isolating the organism (Sorbitol MacConkey or CHROMagar media), Antisera or latex agglutination, Immunoassays.	Cooking meat thoroughly, prevention of cross-contamination
Hepatitis A virus (HAV)	15 to 50 days	Anorexia, nausea, abdominal discomfort, malaise, diarrhea, fever, dark colored urine, and jaundice. Arthritis, urticarial rash and aplastic anemia in rare cases	Consumption of contaminated water or food. Shellfish, clams, oysters, fruits, vegetables, iced drinks, lettuce, and salads.	Serum test for IgM antibodies to HAV, Serum test for Alanine transaminase (ALT), Aspartate aminotransferase (AST) and bilirubin	Washing hands after using toilet and before preparing food
Listeria monocytogenes	2 days to 3 weeks	Diarrhea, nausea, fever, muscular pain, flu-like symptoms in pregnant females (may result in preterm birth or still birth). Meningitis and septicemia may occur in older age or immunocompro-mised patients	Unpasteurized milk, cheese prepared with unpasteurized milk, vegetables, meats, hotdogs, and seafood	Blood culture, cerebrospinal fluid cultures, detection of antibodies to listerolysin O.	Pasteurization of dairy products, cooking foods properly, prevention of cross-contamination.

Organism	Incubation Period	Clinical Features	Possible contaminants	Laboratory diagnosis	Preventive measures
Noroviruses	Between 12 and 48 hours (average, 36 hours); duration, 12-60 hours	Nausea, vomiting, diarrhea, abdominal cramps, headache, and fever	Raw food products, contaminated food or drinking water. Shellfish, oysters and salads.	Stool culture, nucleic acid hybridization, Reverse transcription polymerase chain reaction (PCR), Electron microscopy, Enzyme , and Immunoassays (ELISA).	Proper sewage disposal, water chlorination, restricting infected food handlers from handling food
Salmonella sp.	Non-Typhi: 1 to 3 days Typhi: 3 to 60 days	Non- Tyhi: Nausea, diarrhea, abdominal pain, and fever Typhi: fever, headache, shivering, loss of appetite, malaise, constipation, and muscular pain	Contaminated egg; poultry; meat; unpasteurized milk, dairy foods and fruit juice; raw fruits and vegetables.	Non –Typhi: Stool culture Typhi: Stool culture and blood culture	Cooking food thoroughly, prevention of cross-contamination.
Shigella sp.	12 to 50 hours	Vomiting, abdominal pain, diarrhea with blood and mucus, and fever	Contaminated food or drinking water. Raw vegetables, salads, dairy foods, and poultry.	Stool culture	Practicing proper washing and hygienic techniques in food preparation
Staphylococcus aureus (preformed enterotoxin)	1 to 6 hours	Nausea, vomiting, abdominal pain, fever and diarrhea.	Inappropriately refrigerated foods such as meat, salads, salad dressing, cream pastries, cream-filled baked products, poultry, gravy, and sandwich fillings	Stool or vomitus test for detection of toxin. Suspected food may be tested to detect toxin	Refrigerating foods properly, using hygienic practices
Vibrio cholerae (O1, O139) (non- O1 or non O139)	4 hours to 4 days	Severe watery diarrhea, abdominal cramps, nausea vomiting, headache, fever, and chills. Severe dehydration and death may occur.	Contaminated water, shellfish and crustaceans	Stool culture	Cooking food thoroughly

Organism	Incubation Period	Clinical Features	Possible contaminants	Laboratory diagnosis	Preventive measures
Vibrio parahaemolyticus	2 to 48 h	Watery diarrhea, abdominal pain, nausea, and vomiting	Raw or undercooked seafood from contaminated seawater	Stool culture	Cooking food thoroughly, practicing hygienic techniques in food preparation and storing food at the appropriate temperatures
Yersinia enterocolitica	1 to 3 days	Diarrhea, vomiting, fever, and abdominal cramps	Contaminated meat and milk, undercooked pork, unpasteurized milk, and contaminated water.	Stool culture, blood culture.	Pasteurization of milk; Cooking food thoroughly, prevention of cross-contamination, practicing hygienic techniques in food preparation

Table 1. Causative agents, clinical features and preventive measures for common foodborne illnesses

6. Foodborne illness outbreaks

Manifestation of the same symptoms or illness by two or more of the individuals after consumption of the same contaminated food, is labeled as an outbreak of foodborne illness (The Food Safety and Inspection Service (FSIS), 2008). The outbreak can be recognized when several people who ate together at an occasion become sick and have similar clinical manifestations. Most of the outbreaks are localized, such as an outbreak after eating a catered meal or at a restaurant. However, more widespread outbreaks also occur that affect people in various places, and may last for several weeks (FSIS, 2008).

An outbreak is investigated by describing it systematically and trying to find out the causative agent. The description of outbreak includes time, place, and person distribution. Data is collected by interviews, by testing suspected food source, and by gathering other related information (FSIS, 2008). It is important that foodborne illness outbreaks are investigated timely and proper environmental assessments are done so that appropriate prevention strategies are identified (Lynch, Tauxe, & Hedberg, 2009). According to CDC, the etiology of majority (68%) of reported foodborne-illness outbreaks is unknown. The causative agent of many of the outbreaks cannot be determined because of certain issues related to outbreak investigations e.g. lack of timely reporting, lack of resources for investigations and other priorities in health departments. In addition, ill persons who do not seek health care and limited testing of specimens are also the contributory factors in failure to determine the cause of foodborne illness outbreak (Lynch et al., 2009).

A number of foodborne illness outbreaks are reported from various parts of the world. Analysis of foodborne outbreak data helps in the estimation of the proportion of human cases of specific enteric diseases attributable to a specific food item (Greig & Ravel, 2009). Worldwide, a total of 4093 foodborne outbreaks occurred between 1988 and 2007. It was found that *Salmonella* Enteritidis outbreaks were more common in the EU states and eggs were the most frequent vehicle of infection. Poultry products in the EU and dairy products in the United States, were related to *Campylobacter* associated outbreaks. In Canada, *Escherichia coli* outbreaks were associated with beef. In Australia and New Zealand, *Salmonella* Typhiumurium outbreaks were more common (Greig & Ravel, 2009). Daniels and colleague (2002) conducted a study in the United States, to describe the epidemiology of foodborne illness outbreaks in schools, colleges and universities. The data from January 1, 1973, to December 31, 1997 was reviewed. Characteristics of ill persons, the magnitude of foodborne illness outbreaks, causative agents, food vehicles for transmitting infection, place of preparing food and contributory factors for occurrence of outbreaks, were examined. A total of 604 outbreaks of foodborne illness were reported during the study period. In majority (60%) of the outbreaks the etiology was unknown. Among the outbreaks with a known etiology, in 36% of outbreak reports Salmonella was the most commonly identified pathogen. Foods containing poultry, salads, Mexican-style food, beef and dairy foods were the most commonly implicated vehicles for transmission (Daniels et al., 2002). A total of 6,647 outbreaks of foodborne illness were reported during 1998-2002 in U.S (Lynch, Painter, Woodruff, & Braden, 2006). As a result of these outbreaks, 128,370 persons were reported to become ill. The etiology was identified in 33% outbreaks. The largest percentage of outbreaks was caused by bacterial pathogens and *Salmonella* Enteritidis was the most common causative agent. However, the highest mortality was caused by *Listeria monocytogenes*. Viral pathogens were responsible for 33% of the outbreaks. Among the viral pathogens, norovirus was the most common causative agent (Lynch et al., 2006). In 2002, a salmonellosis outbreak occurred in five states of U.S. It occurred after consuming ground beef. During this outbreak, forty seven cases were reported; out of which 17 people were hospitalized and one death was reported (FSIS, 2008).

Systematic surveillance systems are very important to get information about causative organisms, sources of infection and modes of transmission in foodborne illness (O'Brien et al., 2006). An electronic surveillance system (SurvNet) was established for monitoring and investigation of infectious disease outbreaks, in 2001, in Germany (Krause et al., 2007). During 2001–2005, a total of 30,578 outbreaks were reported. These outbreaks ranged in size from 2 to 527 cases. The most common settings for outbreaks in 2004 and 2005 were households, nursing homes, and hospitals (Krause et al., 2007). In England and Wales, systematic national surveillance of outbreaks of infectious intestinal disease (IID) was introduced in 1992. This system provides information on etiologic agent, sources of infection and modes of transmission. Between January 1, 1992 and January 31, 2003, a total of 1763 outbreaks of IID were reported (O'Brien et al., 2006). From 1992 to 2008, 2429 foodborne outbreaks were reported in England and Wales. Approximately half of the outbreaks were caused by *Salmonella* spp. Poultry and red meat was the most commonly implicated foods in the causation of outbreaks. The associated factors in most outbreaks were cross-contamination, lack of adequate heat treatment and improper food storage (Gormley et al., 2011). In central Taiwan, 274 outbreaks of foodborne illness including 12,845 cases and 3 deaths were reported during 1991 to 2000. Majority (62.4%) of the outbreaks were caused by bacterial pathogens. The main etiologic agents were *Bacillus cereus*, *Staphylococcus aureus*, and *Vibrio parahaemolyticus*. The important contributing factor was improper handling of food. The implicated foods included seafood, meat products and cereal products (Chang & Chen, 2003).

A review of *E. coli* O157 outbreaks reported to CDC from 1982 to 2002, was conducted (Sparling, Crowe, Griffin, Swerdlow, & Rangel, 2005). During the study period, 49 states reported 350 outbreaks. During these outbreaks 8,598 cases were reported; out of which 1,493 (17%) were hospitalized, and 40 (0.5%) died. Transmission route for 183 (52%) was foodborne and the food vehicle for 75 (41%) foodborne outbreaks was ground beef (Sparling et al., 2005).

In a review of all confirmed foodborne outbreaks reported to the Centers for Disease Control and Prevention (CDC) from 1982 to 1997, a total of 2,246 foodborne outbreaks were reported; 697 (31%) were of known etiology. *Salmonella* was responsible for 65% of outbreaks with a known etiology (Hedberg et al., 2008). An analysis of national foodborne outbreak data from 1973 through 2001for determining the proportion of *Salmonella* Heidelberg outbreaks and its causes was conducted (Chittick, Sulka, Tauxe, & Fry, 2006). Out of 6,633 outbreaks with known etiology, *Salmonella* Heidelberg was responsible for 184 (3%) outbreaks. 53 outbreaks were poultry or egg-related (Chittick et al., 2006). Because of increasing consumption of fresh produce, changes in production and distribution, there is an increase in foodborne outbreaks caused by contaminated fresh produce (Lynch et al., 2009; Sivapalasingam et al., 2004). An analysis of data for 1973 through 1997 from the Foodborne Outbreak Surveillance System was conducted. A total of 190 outbreaks were reported including 16,058 illnesses, 598 hospitalizations, and eight deaths. There was an increase in the proportion of produce-associated outbreaks, rising from 0.7% in the 1970s to 6% in the 1990s. The food items most frequently implicated in the outbreaks associated with fresh produce include salad, lettuce, juice, melon, sprouts, and berries. In this analysis, the bacterial pathogens were the most common causative agents. Among the bacterial pathogens *Salmonella* was the commonest causative agent (Sivapalasingam et al., 2004). In a study carried out from October 2004 to October 2005 in Catalonia, Spain, 181 outbreaks were reported; 72 were caused by *Salmonella* and 30 by norovirus (NoV); 66.7% of NoV outbreaks occurred in restaurants. Hospitalizations were reported more commonly in outbreaks caused by bacterial pathogens as compared to those caused by NoV (Martinez et al., 2008).

In Spain, 971 and 1227 outbreaks were reported in 2002 and 2003, respectively. A substantial proportion of outbreaks were associated with consumption of eggs and egg products (Crespo et al., 2005). A study was conducted in northeastern Spain to investigate the trend of foodborne *Salmonella*-caused outbreaks and number of cases, hospitalizations, and deaths. A review of the information on reported outbreaks of foodborne disease from 1990 to 2003 found a total of 1,652 outbreaks. 1,078 outbreaks had a known etiologic agent; out of which 871 (80.8%) were caused by *Salmonella*, with 14,695 cases, 1,534 hospitalizations, and 4 deaths. Forty-eight percent of *Salmonella*-caused outbreaks were associated with consumption of eggs. The study concluded that to prevent and control these outbreaks, health education programs are needed to create awareness regarding risk of consuming raw or undercooked eggs (Domínguez et al., 2007).

In 2002, in the Netherlands a national study of foodborne illness outbreaks was performed (van Duynhoven et al., 2005). A total of 281 foodborne illness outbreaks were included. Most of these outbreaks were reported from nursing homes, restaurants, hospitals and day-care centers. In restaurant outbreaks, food was the mode of transmission in almost 90% outbreaks. The causative agents included norovirus (54%), Salmonella spp. (4%), rotavirus (2%), and Campylobacter spp. (1%) (van Duynhoven et al., 2005). The Danish and Dutch investigation reported foodborne outbreaks caused by the same strain of *Salmonella* serotype Typhimurium DT104 during the year 2005. These were two distinct outbreaks caused by the same organism. The outbreaks were traced to two kinds of raw beef provided by the same supplier (Ammon & Tauxe, 2007).

A study conducted in Qassim province, Saudi Arabia, analyzed the foodborne illness surveillance data for the year 2006. During the study period, 31 foodborne illness outbreaks comprising of 251 cases, were reported. The most common etiologic agent was *Salmonella* spp, followed by *Staphylococcus* aureus. Commercially prepared foods were consumed by the majority (68.9%) of the cases. Meat and Middle Eastern meat sandwich were the commonly implicated food vehicles (Al-Goblan & Jahan, 2010).

The globalization of the food industry has resulted in occurrence of international viral foodborne outbreaks (Verhoef et al., 2009). Although mostly the bacterial pathogens are targeted for prevention of foodborne illness, yet it is suspected that noroviruses (NoV) are the most common cause of gastroenteritis. The role of NoV in foodborne illness has become evident because of new molecular assays. An analysis of 8, 271 foodborne outbreaks reported to CDC from 1991 to 2000 showed an increase in the proportion of NoV-confirmed outbreaks. It rose from 1% in 1991 to 12% in 2000. In addition, NoV outbreaks were larger in magnitude as compared to the bacterial outbreaks (Widdowson et al., 2005).

The Belgian data for foodborne norovirus (NoV) outbreaks showed that in 2007, 10 NoV foodborne outbreaks were reported accounting for 392 cases in Belgium. NoV was the most commonly identified agent in foodborne outbreaks. Sandwiches were the most commonly implicated food. A review of forty outbreaks due to NoV, from 2000 to 2007 revealed that the food handler was responsible for the outbreak in 42.5% of the cases. The source of transmission was water (27.5%), shellfish (17.5%) and raspberries (10.0%) in remaining cases (Baert et al., 2009).

The contributory factors observed in most of the foodborne illness outbreaks included poor personal hygiene, inadequate holding times and temperatures, cross-contamination, lack of adequate heat treatment and improper food storage (Chang & Chen, 2003; Gormley et al., 2011; Hedberg et al., 2008).

7. Emerging foodborne infections

The changes in the methods of food production have affected the epidemiology of foodborne infection (Tassios & Kerr, 2010). Various new pathogens have emerged due to changing production processes in food industry. Some of these are new pathogens and were unknown previously, others are emerging pathogens for foodborne infections, and some others are evolving pathogens that have become more potent (Mor-Mur & Yuste, 2009). These pathogens include *Campylobacter jejuni, Salmonella* Typhimurium DT104, enterohemorrhagic *Escherichia coli, Listeria monocytogenes, Arcobacter butzleri, Mycobacterium avium* subsp. *Paratuberculosis,* etc. *Campylobacter jejuni* O:19 and other serotypes may cause neuropathy called Guillain–Barré syndrome. Multi-drug resistant *Salmonella* Typhimurium DT104 and other serotypes may cause salmonellosis leading to chronic reactive arthritis. Enterohemorrhagic *Escherichia coli* infection can cause complications such as hemolytic uremic syndrome and thrombotic thrombocytopenic purpura. *Listeria monocytogenes* causes listeriosis, a public health problem of major concern due to severe non-enteric nature of the disease i-e, meningitis or meningoencephalitis, and septicemia. *Arcobacter butzleri* is isolated from raw poultry, meat, and meat products and is considered a potential foodborne pathogen. *Mycobacterium avium* subsp. *paratuberculosis* may contribute to Crohn's disease (Mor-Mur & Yuste, 2009).

The new emerging foodborne infections are also related to food handling practices. Foodborne infections caused by *Escherichia coli* O157, *Yersinia enterocolitica, Campylobacter* and *Vibrio*, are associated with processing and packaging of food, or the importation of certain food from a new geographical area (Robinson, 2007). The well known foodborne pathogens may develop antimicrobial resistance and generate new public health challenges (Newell et al., 2010). Antimicrobial resistance has developed in many bacterial foodborne pathogens, such as *Salmonella*, *Shigella, Vibrio* spp., *Campylobacter*, methicillin resistant *Staphylcoccus aureas*, *E. coli* and *Enterococci*.

Previously un-recognized foodborne pathogens are constantly emerging. The emerging viral foodborne infections include norovirus, hepatitis A, rotaviruses and SARS (Newell et al., 2010). Currently, the norovirus (NoV) and hepatitis A virus (HAV) are considered the most important human foodborne pathogens. NoV and HAV are highly infectious and may cause large outbreaks (Koopmans & Duizer, 2004). Hepatitis E causes substantial morbidity in many developing countries while in developed countries, it was previously thought to be confined to travelers returning from endemic areas (Dalton, Bendall, Ijaz, & Banks, 2008). However, this concept is changing based on the evidence available. In developed countries, Autochthonous hepatitis E is found to be quite common and affects older age groups leading to morbidity and mortality (Dalton et al., 2008).

8. Monitoring and surveillance of foodborne illness

Worldwide, there are various surveillance systems to monitor, investigate, control and prevent illness. To assess and monitor morbidity and mortality in the United States, surveillance activities are conducted by several systems in collaboration with federal agencies and health departments (McCabe-Sellers & Beattie, 2004). Some surveillance systems are specific for foodborne illnesses. In addition to monitoring the foodborne illness, these surveillance activities also help in evaluating the safety of the food supply (Allos et al., 2004). Some of these surveillance systems are discussed below:

8.1 FoodNet (Foodborne disease active surveillance network)

FoodNet is the surveillance system in the United States. For Foodnet, CDC has collaborated with ten Emerging Infections Program (EIP) sites (California, Colorado, Connecticut, Georgia, New York, Maryland, Minnesota, Oregon, Tennessee and New Mexico), the US Department of Agriculture, and the Food and Drug Administration. It performs active surveillance for foodborne illnesses and also conducts epidemiologic studies to determine the changing epidemiology of foodborne illnesses. It responds to new and emerging foodborne illnesses, monitors the burden of foodborne illnesses, and identifies their sources (FSIS, 2008).

Figure 2 shows the burden of illness pyramid. It helps in understanding foodborne disease reporting in FoodNet surveillance system. It shows steps involved in the registration of an episode of foodborne illness in the population. Moving from bottom to top of pyramid, the steps are: exposure of some individuals in the general population to an organism; out of the exposed some persons become ill; out of all ill some seek medical care; a specimen is obtained from some of these persons and sent to a clinical laboratory; some of these specimens are tested for a specific pathogen; the causative organism is identified in some of these tested specimens; a local or state health department receives the report of the laboratory-confirmed case (CDC, 2011c).

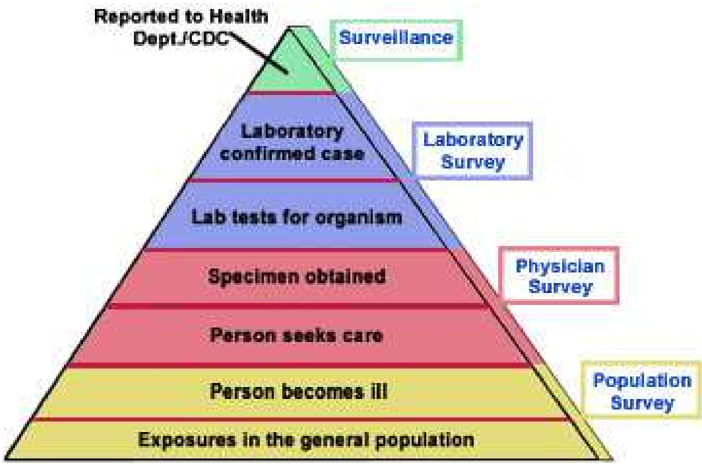

Fig. 2. FoodNet surveillance, burden of illness pyramid. Adapted from CDC. Available at: http://www.cdc.gov/foodnet/surveillance_pages/burden_pyramid.htm. Accessed August 04, 2011.

8.2 PulseNet (The molecular subtyping network for foodborne bacterial disease surveillance)

In the United States, PulseNet has created a national framework for pathogen-specific surveillance (Li et al., 2010). PulseNet is responsible for molecular subtyping of foodborne illness surveillance. It helps in detecting widespread foodborne outbreaks by comparing strains of bacterial pathogens from all over the United States. It performs DNA "fingerprinting" on foodborne bacteria by pulsed-field gel electrophoresis. By identifying and labeling each "fingerprint" pattern, it is possible to rapidly compare these patterns through an electronic database at the CDC, thus identifying related strains (FSIS, 2008).

8.3 Electronic Foodborne Outbreak Reporting System (eFORS)

The Electronic Foodborne Outbreak Reporting System's (eFORS) database is a surveillance system that collects reports on foodborne outbreaks. It requires specialized knowledge and expertise to appropriately analyze and interpret the data (Middaugh, Hammond, Eisenstein, & Lazensky, 2010). Various studies are conducted by analyzing the data collected within the Electronic Foodborne Outbreak Reporting System (eFORS) in various settings, such as schools in order to examine the magnitude of foodborne illness, their etiologies and to provide recommendations for prevention of foodborne illness (Venuto, Halbrook, Hinners, & Mickelson, 2010).

9. Strategies for control of foodborne illness

The contamination of food is influenced by multiple factors and may occur anywhere in the food production process (Newell et al., 2010). However, most of the foodborne illnesses can be traced back to infected food handlers. Therefore, it is important that strict personal hygiene measures should be adopted during food preparation. To prevent foodborne infections in children, educational measures are needed for parents and care-takers. The interventions should focus on avoiding exposure to infectious agents and on preventing cross-contamination (Marcus, 2008).

Good agriculture practice and good manufacturing practice should be adopted to prevent introduction of pathogens into food products (Koopmans & Duizer, 2004). In order to control foodborne viral infections, it is important to increase awareness of food handlers regarding the presence and spread of these viruses. In addition, standardized methods for the detection of foodborne viruses should be utilized and laboratory-based surveillance should be established for early detection of outbreaks (Koopmans & Duizer, 2004).

To prevent food-related zoonotic diseases, collaboration between public health, veterinary and food safety experts should be established. This collaboration will help in monitoring trends in the existing diseases and in detecting emerging pathogens. It will help in developing effective prevention and control strategies (Newell et al., 2010). The control strategies should be based on creating awareness among the consumers, farmers and those raising farm animals. The improvement of farming conditions, the development of more sensitive methods for detection of pathogens in slaughtered animals and in food products, and proper sewage disposal are other intervention strategies (Pozio, 2008). Hygienic measures are required throughout the continuum from “farm to fork”. Further research is also required to explore pathways of the foodborne illness and to determine the vehicles of the greatest importance (Unicomb, 2009).

In a study conducted in Turkey, knowledge, attitudes, and practices about food safety among food handlers, were explored. The study revealed that food handlers in Turkish food industry often lacked knowledge regarding basic food hygiene. The authors concluded that the food handlers must be educated regarding safe food handling practices (Bas, Safak Ersun, & KIvanç, 2006). For the prevention of foodborne outbreaks, training of food handlers, regarding appropriate preparation and storage of food is required. In addition, effective environmental cleaning and disinfection, excluding infected staff, implementing hand hygiene principles, and preventing cross-contamination are recommended (Greig & Lee, 2009).

Proper processing of food is necessary to ensure the reduction or elimination of the growth of harmful microorganisms. Pasteurization of milk and dairy products and hygienic manufacturing processes for canned foods will help reduce the cases of food-borne illnesses. Food irradiation is a recent technology for prevention of food-borne illnesses. The food irradiation methods include Gamma irradiation, Electron beam irradiation, and X-irradiation. Irradiation destroys the organism’s DNA and prevents DNA replication. Food irradiation could eliminate *E. coli* in ground beef, *Campylobacter* in poultry, *Listeria* in food and dairy products, and *Toxoplasma gondii* in meat. However, all food products cannot be irradiated (Linscott, 2011).

The consumers should also take precautions to prevent foodborne illnesses. These include cooking meat, poultry, and eggs at appropriate temperatures; proper refrigeration and storage of foods at recommended temperatures; prevention of cross-contamination of food; use of clean slicing boards and utensils while cooking; and washing hands often while preparing food (Linscott, 2011).

10. Conclusion

Globally, foodborne illnesses are responsible for substantial morbidity and mortality. Although it is difficult to determine the exact mortality associated with foodborne illnesses, worldwide an estimated 2 million deaths occurred due to gastrointestinal illness during the year 2005. Foodborne illnesses result from consumption of food containing pathogens or the food contaminated by poisonous chemicals or toxins. Foodborne illnesses also play an important role in new and emerging infections. Various new pathogens have emerged due to changing dynamics of food industry. It is estimated that during past 60 years, approximately 30% of all emerging infections comprised of pathogens transmitted through food.

It is important to monitor and investigate the foodborne illnesses in order to control and prevent them. For this purpose various surveillance systems are established in different parts of the world. FoodNet, PulseNet and EFORS are the surveillance systems for monitoring foodborne illness in the United States. These surveillance systems play vital role in prevention, early detection and control of foodborne illness outbreaks.

The contamination of food is influenced by multiple factors and may occur anywhere along the food chain. Good agriculture practice and good manufacturing practice should be adopted to prevent introduction of pathogens into food products. Most foodborne illnesses can be tracked to infected food handlers. Therefore, it is important that strict personal hygiene measures should be adopted during food preparation. The consumers should also take precautions for prevention of foodborne illness. These include cooking food at appropriate temperatures and following standard hygiene practices, proper storage and prevention of cross-contamination of food. Thus integrated intervention strategies are required to prevent foodborne illness at community level. Successful implementation of these interventions requires inter-sectoral collaboration including agriculture industry, food industry and health care sector.

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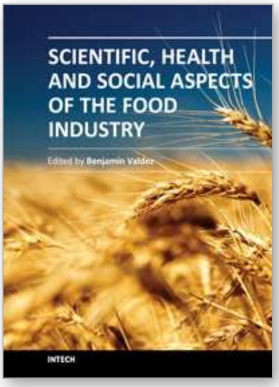

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This book presents the wisdom, knowledge and expertise of the food industry that ensures the supply of food to maintain the health, comfort, and wellbeing of humankind. The global food industry has the largest market: the world population of seven billion people. The book pioneers life-saving innovations and assists in the fight against world hunger and food shortages that threaten human essentials such as water and energy supply. Floods, droughts, fires, storms, climate change, global warming and greenhouse gas emissions can be devastating, altering the environment and, ultimately, the production of foods. Experts from industry and academia, as well as food producers, designers of food processing equipment, and corrosion practitioners have written special chapters for this rich compendium based on their encyclopedic knowledge and practical experience. This is a multi-authored book. The writers, who come from diverse areas of food science and technology, enrich this volume by presenting different approaches and orientations.