CHAPTER 2

Literature Review

2.1 Discovery of *Campylobacter*

Although *Campylobacter* was discovered and named in 1970s, the long-time history of this agent have been started for centuries ago but the evidence of findings was discovered later in 1985 (Kist, 1985 (as cited in Butzler, 2004); Kist, 1986). The series of articles have been published in German language in the *Münchener Medizinische Wochenschrift* since 1886 by Theodor Escherich describing spiral bacteria from stool specimens of children with diarrhea (Kist, 1985 (as cited in Altekruse, Stern, Fields, & Swerdlow, 1999)). At that time, the bacteria were called "cholera infantum" (Escherich, 1886 (as cited in Butzler, 2004)). Even the bacteria were observed microscopically in stool specimens with spiral shape, He failed to culture them on solid medium.

Campylobacter seemed to be firstly explored in animals by veterinarians, but the agent was not clearly known and named as *Campylobacter* as nowadays, with several names proposed. The agent had been more observed in animals with the majority of abortion. Bacterial isolates from sheep aborted fetuses which resemble a vibrio, called related *Vibrio*, was reported by McFadyean and Stockman in 1913 (Kist, 1985 (as cited in Altekruse et al., 1999)). In 1919, bacterial isolates from aborted bovines in the USA was described as a spirillum by Smith, who later assumed that the bacterium he studied was the same as McFadyean and Stockman findings, and later confirmed the agent together with Taylor and named "*Vibrio fetus*" (Smith & Taylor, 1919). Gastrointestinal symptoms had been reported and the term "*Vibrio*" had been widely used regard to similar organism. In 1931, Jones, Orcutt, and Little reported winter dysentery in calves attributed to infection with bacterium they called "*Vibrio jejuni*" (Jones, Orcutt, & Little, 1931) and similar organism was described by Doyle in 1944 associated dysentery in swine (Doyle, 1944 (as cited in Butzler, 2004)). In 1949, pathogenic role of *V. fetus veneralis* was described by Stegenga and Terpstra regarding enzootic sterility in cows (Stegenga &

Terpstra, 1949 (as cited in Butzler, 2004)). Ten years later, in 1959, *V. fetus* was differentiated into two types, *V. fetus venerealis* and *V. fetus intestinalis*, by Florent who distinguished the agent using chemical and pathogenic characteristics (Florent 1959 (as cited in Butzler, 2004)).

Infection of *Campylobacter* in human was first well-documented in Illinois. In 1938, milk-borne outbreak diarrhea affected over 300 of inmates in two adjacent state institutions. Approximate 10 percent of fecal samples were microscopically observed positive resembling *V. jejuni* while fecal cultures were negative. Some of the blood samples were able to grow in broth media (Levy, 1946). In 1947, *V. fetus* from the blood of three pregnant women with unknown cause of fever was isolated by Vinzent, Dumas, and Picard (Vinzent, Dumas, & Picard, 1947 (as cited in Butzler, 2004)). After 4 weeks of infection, two of them aborted. In 1957, King observed different biochemical and antigenic characteristics of the agent described by Vinzent (King, 1957; King, 1962 (as cited in Butzler, 2004)). She named the organism "related *Vibrio*" (Kist, 1985 (as cited in Altekruse et al., 1999)). However, 15 years later, only 12 cases related to this organism, later renamed as *Campylobacter* by Sebald and Véron, were reported in the literature (Butzler, 2004). Selective culture techniques for bacterial isolation from fecal samples were suspected to be the causative factor.

In 1972, the success of *Campylobacter* isolation from fecal samples was published by Dekeyser and Butzler (Kist, 1985 (as cited in Altekruse et al., 1999)). The samples were firstly isolated using a special filtration technique that allowed only *Campylobacter* bacteria to pass through and then inoculated on to a selective medium. This first fecal culture was proved that intestinal infection was the origin of *Campylobacter* bacteremia (Dekeyser, Gossuin-Detrain, Butzler, & Sternon, 1972 (as cited in Butzler, 2004)). A collaboration of Dekeyser and Butzler was the starting point of detection the agent in stools of diarrhea patients. In 1973, first case of Campylobacter enteritis was reported in Africa in Zaire, where now known as the Democratic Republic of Congo (Butzler, 1978 (as cited in Butzler, 2004)). Development of new selective media decreased the need of filter suspensions and allowed *Campylobacter* effortlessly to be isolated (Altekruse et al., 1999). In 1979, the first Campylobacter enteritis in human was fully published (Butzler & Skirrow, 1979 (as cited in Butzler, 2004)). After Kist reported Escherich's findings at the Third International *Campylobacter* Workshop in Ottawa in 1985, seemed to be the

first finding of *Campylobacter* in human, nowadays, more cases of *Campylobacter* infection have been reported throughout the world. The organism is considered to be the major common cause of bacterial gastroenteritis in human (WHO, 2013). Historical timeline of *Campylobacter* discovery was shown in Figure 2.1.

2.2 Characteristics of *Campylobacter jejuni*

Campylobacter jejuni is a gram-negative, spirally curved bacilli, microaerophilic, non-spore forming bacterium with approximately 0.2-0.8 μm × 0.5-5 μm (Bolton, 2015). It has a corkscrew motility pattern. The species of *Campylobacter* can be found in the intestine of wild and domestic animals, especially in poultry (Levin, 2007). Among 14 species and 6 subspecies of *Campylobacter* that cause illness in human, *Campylobacter jejuni* is the agent that considered to cause gastroenteritis and severe acute extra-intestinal illness called "Guillain–Barré syndrome" that results in ascending muscle weakness, begins in the lower extremities and moves upward, and paralysis (O'brien, 2017). In some severe cases, the progress of the illness may cause respiratory failure leads to death (van den Berg, Bunschoten, van Doorn, & Jacobs, 2013).

Phenotypic characterization of the microorganism is based on biochemical tests, patterns of antimicrobial resistance, and growth temperature (Levin, 2007). *C. jejuni* gave positive results to catalase and indoxyl acetate. Most of *Campylobacter* is susceptible to nalidixic acid and resistant to cephalothin (Barrett, Patton, & Morris, 1988). *C. jejuni* (subspecies *jejuni*) and *C. coli* are the most leading species among *Campylobacter* in public health concerns that cause gastroenteritis in human (WHO, 2016) and more likely to differentiate the two species with biochemical tests by using hydrolysis of hippurate (International Organization for Standardization [ISO], 2006). Other phenotypic characteristics such as oxidase positive, motility (81%), nitrate reduction, capability to grow on MacConkey's agar, growth in 1% glycine, and unable to utilize glucose (Hunt, Abeyta, & Tran, 2001). In addition, the thermophilic *C. jejuni* requires temperature between 37 and 42 ^{o}C to grow (Davis & DiRita, 2008) with the optimum temperature at 41.5 ^{o}C (ISO, 2006). The bacteria are incapable to grow below 30 ^{o}C since cold shock protein genes were absent (Hazeleger, Wouters, Rombouts, & Abee, 1998). The optimum growth occurs at water activity (a_w) 0.997 with approximately 0.5% w/v NaCl and growth does not occur at water activity lower than 0.987 (New Zealand Ministry of Health, 2001).

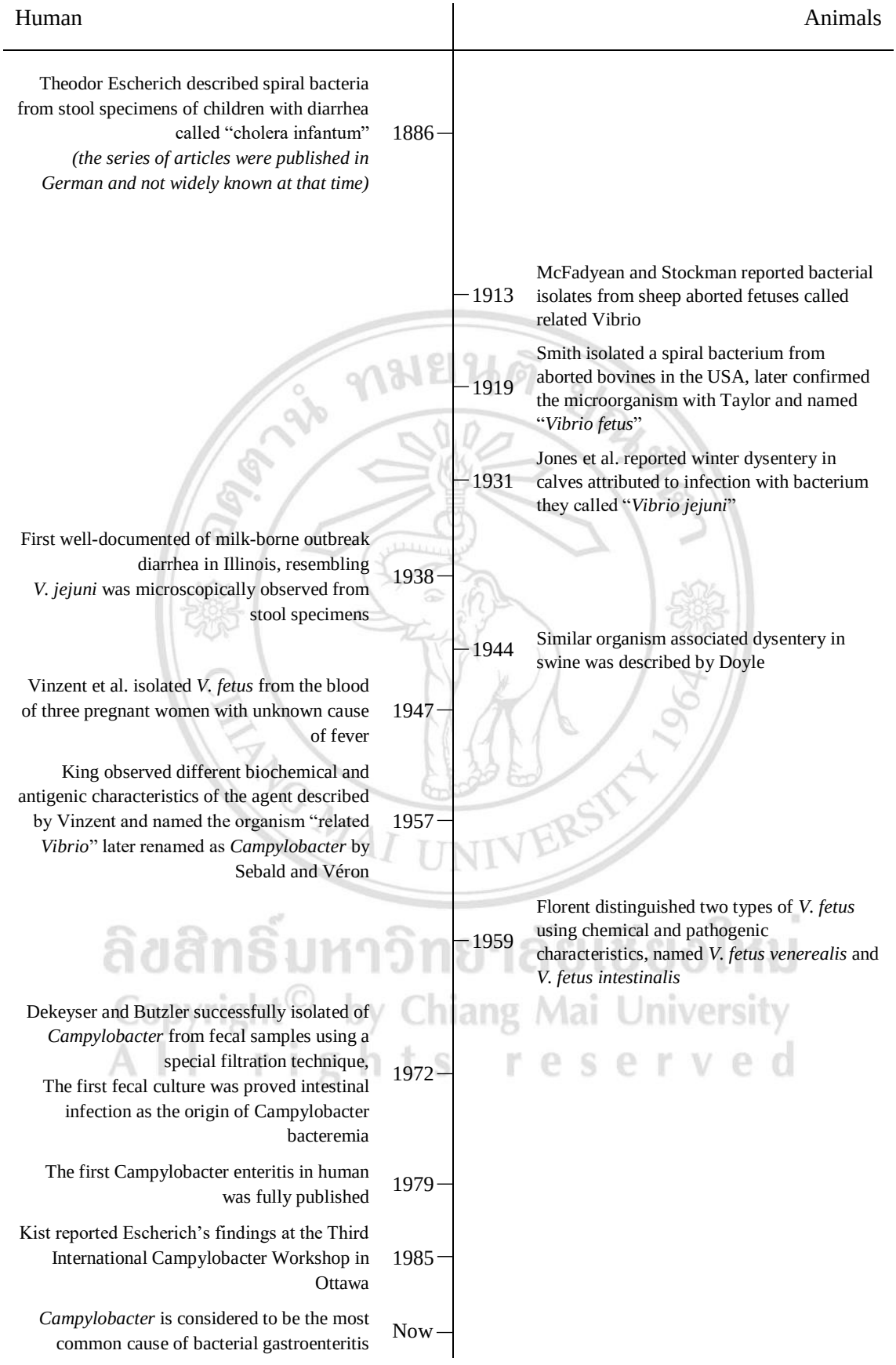

Figure 2.1 Historical timeline of *Campylobacter* discovery

The organisms are sensitive to concentrations of sodium chloride (NaCl) greater than 2%w/v (New Zealand Ministry of Health, 2001). *Campylobacter* best grows in low oxygen conditions, 5% O_2, 10% CO_2 and 85% N_2 (Davis & DiRita, 2008), and optimum pH is 6.5-7.5 (ESR, 2001). If the agent has unfavorable growth conditions, the cells are viable but non-culturable (VBNC) (Li, Mendis, Trigui, Oliver, & Faucher, 2014).

2.3 Campylobacteriosis as a public health concern

Campylobacter spp., especially *C. jejuni* and *C. coli*, are now recognized as the most frequent cause of bacterial gastroenteritis in human (WHO, 2013). In industrialized countries, even incidences of campylobacteriosis were reported regularly, the true incidence remains underestimated due to undiagnosed or unreported cases (Humphries & Linscott, 2015). In developing countries, diagnosis of campylobacteriosis and incidence reports still not be widely published because national surveillance programs do not exist. Most estimated data available were collected from laboratory-based research (Coker, Isokpehi, Thomas, Amisu, & Obi, 2002). Campylobacteriosis is considered an endemic disease in some regions because of the constantly present in a population. From a review of Kaakoush et al. (2015) incidence and prevalence of campylobacteriosis from *C. jejuni* or *C. coli* may vary considerably as shown in Table 2.1. Infection with *C. jejuni* or *C. coli* can be occurred in all ages, but mostly reported in children less than 4 years (Nielsen, Ejlertsen, Engberg, & Nielsen, 2013; Sadkowska-Todys & Kucharczyk, 2016) and young adults (15-24 years) (Nielsen et al., 2013; Schielke, Rosner, & Stark, 2014).

Poultry and cattle are animals considered to be the main reservoirs of *Campylobacter*. Consumption of contaminated food and water is the main sources of transmission. Other transmissions such as direct contact with animals and person-to-person (fecal-oral or via fomites) can occur. Contaminated chicken and dairy products are more likely to report as sources of infections or foodborne outbreaks. Outbreaks of campylobacteriosis usually associated with raw chicken meat and raw milk consumption. An outbreak of campylobacteriosis (*C. jejuni* and *C. coli*) was report in southern Sweden at a wedding reception in May 2012. Consumption of undercooked liver pâté was associated with *C. jejuni* and *C. coli* infections and the source of infection was traced back to producer delivering the liver and confirmed using pulsed-field gel electrophoresis (PFGE) and whole-genome sequencing (Lahti, Löfdahl, Ågren, Hansson, & Olsson

Engvall, 2017). Moreover, a large outbreak of *C. jejuni* in a university college associated with chicken liver pâté in Australia in 2013 was published (Moffatt et al., 2016). A total of 56 gastroenteritis cases were identified with 7 laboratory-confirmed cases of *C. jejuni* and *C. coli* infections. Consumption of a chicken liver pâté entrée was shown a significant association with the illness (relative risk (RR) 3.64, 95% confidence interval (CI) 2.03-6.52, $p<0.001$). Milkborne outbreak in Utah with 99 suspected cases (59 confirmed) of *C. jejuni* infections were reported in 2014 (Davis et al., 2016). Consumption of raw milk as legally sell in this state possess a risk of campylobacteriosis to consumers due to a safe level for routine somatic cell and coliform counts does not guarantee its safety. Other outbreak, in April to May 2014, in the South Western part of Sweden revealed evidence of campylobacteriosis after a preschool visit to a dairy farm associated with drinking of unpasteurized milk (Lahti et al., 2017). *C. jejuni* was isolated from 8 out of total 11 identified gastroenteritis cases. Moreover, drinking untreated water was also reported associated with *Campylobacter* infection (Wilson et al., 2008). Previous publications of campylobacteriosis outbreaks and their sources of infection were shown in Figure 2.2 (Kaakoush et al., 2015).

Table 2.1 Occurrence of campylobacteriosis by countries

Region/Country	Year	Occurrence	Reference
Africa			
Kenya	2005-2007	5% of children with diarrhea	(O'Reilly et al., 2012)
Malawi	1997-2007	21% of children with diarrhea	(Mason et al., 2013)
America			
United States	2009	13.02/100,000 population	(Centers for Disease Control and Prevention [CDC], 2010)
	2012	14.3/100,000 population	(CDC, 2013)
	2015	2.97/100,000 population	(CDC, 2016)
Canada	2014	33.6/100,000 population	(BC Centre for Disease Control, 2015)
Mexico	2006-2007	11.7 per 100 infants and 0 per 100 elderly people	(Zaidi et al., 2012)

Table 2.1 Occurrence of campylobacteriosis by countries (continued)

Region/Country	Year	Occurrence	Reference
Asia			
China	2005-2009	14.9% of gastroenteritis cases in adults	(Chen, Sun, Zeng, & Yu, 2011)
Japan	2005-2006	1,512/100,000 population/year (estimated)	(Kubota et al., 2011)
India	2008-2010	4.5% of gastroenteritis cases	(Mukherjee, Ramamurthy, Bhattacharya, Rajendran, & Mukhopadhyay, 2013)
Israel	2010	90.99/100,000 population	(Weinberger et al., 2013)
Thailand	2000-2003	5% of farm workers with diarrhea 18% children with diarrhea	(Padungtod & Kaneene, 2005)
	2008	1.3% of adult patients with diarrhea	(Pham et al., 2005)
	2012	8.6% of children with diarrhea	(Berger, 2017)
Europe			
Denmark	2009-2010	35/100,000 inhabitants	(Nielsen et al., 2013)
Germany	2010	80/100,000 population	(Schielke, Rosner, & Stark, 2014)
Netherlands	2011	52/100,000 population	(Bouwknegt, van Pelt, & Havelaar, 2013)
Norway	1993-2011	30/100,000 population	(Steens, Eriksen, & Blystad, 2014)
Poland	2013 2014	1.43/100,000 population 1.69/100,000 population	(Sadkowska-Todys & Kucharczyk, 2016)
United Kingdom	2008-2009	Over 500,00 cases/year	(Tam et al., 2011)
Oceania			
Australia	2012	101/100,000 population	(NNDSS Annual Report Writing Group, 2015)
New Zealand	2002-2006 2008	353.8/100,000 population 161.5/100,000 population	(Sears et al., 2011)

A relatively small dose of *C. jejuni* which contains 360-500 organisms was sufficient to cause infections in human (Kothary & Babu, 2001; Hara-Kudo & Takatori, 2011). The onset of the disease was usually observed after 1-3 days of infection. However, low infectious dose of the bacteria may take longer time to develop symptoms (Blaser, 1997). Duration of gastroenteritis symptoms typically lasts 3 to 6 days (WHO, 2016). Naturally, campylobacter is a self-limiting disease in healthy people. People with co-morbidities are more likely to become hospitalized than those without (Harvala et al., 2016). Acute watery or bloody diarrhea, vomiting and abdominal pain are common clinical signs usually seen in *Campylobacter* infected patients as well as fever (Kaakoush et al., 2015). Clinical manifestations of human campylobacteriosis are mainly categorized into 2 groups; gastrointestinal and extragastrointestinal manifestations. Acute enteritis, gastritis, hepatitis, inflammatory bowel disease (IBD) and functional gastrointestinal disorders (FGID) are categorized to gastrointestinal symptoms (Kaakoush et al., 2015; O'brien, 2017). In some cases that have more progress of disease, chronic sequelae and extra-intestinal consequences may be observed such as reactive arthritis (ReA), Guillain–Barré syndrome (GBS), Miller Fisher syndrome (MFS), haemolytic uraemic syndrome (HUS), and meningitis (Kaakoush et al., 2015; O'brien, 2017). In addition, bacteremia can be occurred in immunocompromised patients. Other conditions, namely cancer, liver disease, hypogammaglobinemia, and HIV infections are predisposing factors for *Campylobacter* bacteremia (Hussein et al., 2016).

Guillain–Barré syndrome (GBS) is the autoimmune disorder that occurred after getting infected with *C. jejuni* in some cases. Estimated incidence of GBS worldwide was between 1.1/100,000/year and 1.8/100,000/year (McGrogan, Madle, Seaman, & de Vries, 2009). Estimated 1/3 of number of GBS patients were acquired from *C. jejuni* infections (Poropatich, Walker, & Black, 2010). Ascending muscle weakness begins from extremities and acute paralysis are generally seen in typical cases. An acute neuropathy is progressively occurred in less than 4 weeks after symptoms appeared (Hughes & Cornblath, 2005) and disability can be observed up to 20% of patients who developed persistent weakness after a year (Rees, Thompson, Smeeton, & Hughes, 1998). A study regarding to role of *C. jejuni* infection in the pathogenesis of GBS described that molecular mimicry between sialylated lipo-oligosaccharides on the cell envelope of *C. jejuni* and the structure of gangliosides on human nerves leads to cross-reactive immune

response with human peripheral nerves consequently results in muscular weakness and flaccid paralysis (Nyati & Nyati, 2013).

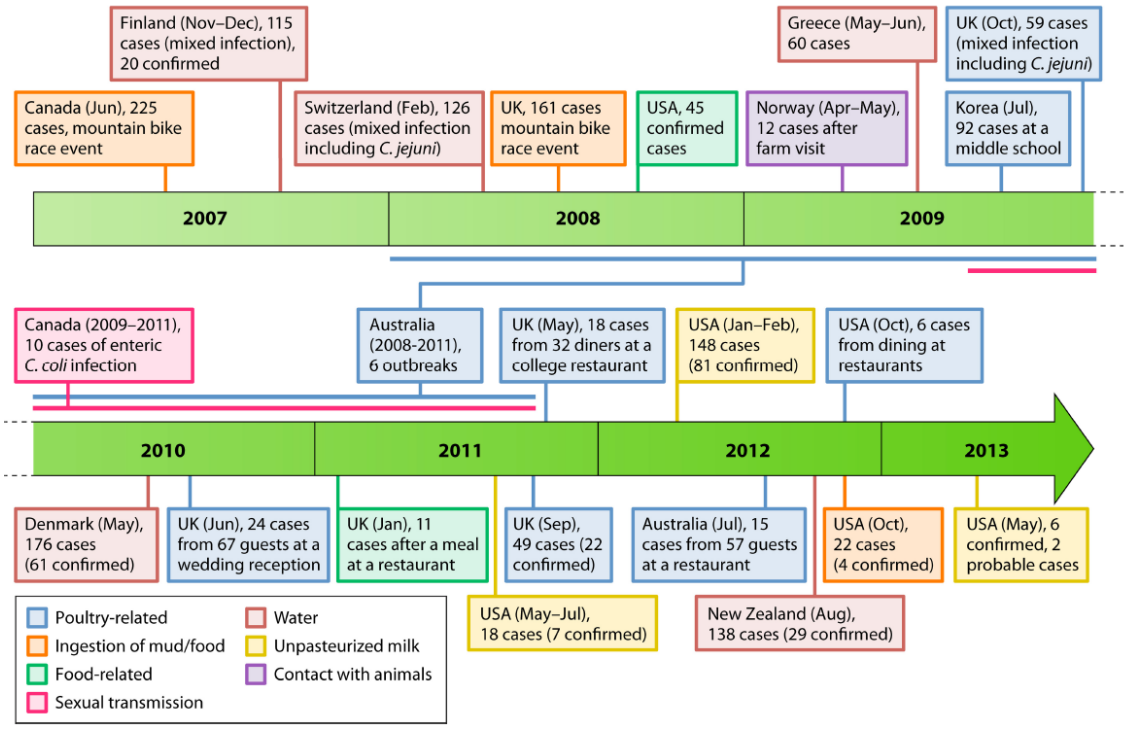

Figure 2.2 Timeline of published campylobacteriosis outbreaks and sources of infection (2007-2013). Reprinted from "Global epidemiology of *Campylobacter* infection", by N. O. Kaakoush et al., 2015, *Clinical microbiology reviews*, *28*(3), p. 692. Copyright 2015 by the American Society for Microbiology.

Campylobacter spp. are estimated to cause 96 million (95% uncertainty interval 52-177 million) of foodborne illness in 2010 (Kirk et al., 2015). The burden of campylobacteriosis regard to diarrheal diseases is high (7.5 million disability-adjusted life year (DALY) or 8.4% of the total burden of diarrheal diseases) and ranks fourth, followed rotavirus (18.7 million DALY), typhoid fever (12.2 million DALY) and cryptosporidiosis (8.3 million DALY) (WHO, 2013). Infection of *C. jejuni* in the USA alone costed to the economic burden over US $4 billion (Wilson et al., 2008). In Europe, €500 per incident and 60 cases per 100,000 population was estimated result in about €30 million annual cost of campylobacteriosis (Duff et al., 2003).

2.4 Poultry as a source of *Campylobacter jejuni* infection

Poultry plays a role as a major source and reservoir for *Campylobacter*, especially the species *jejuni* (Ingmer, 2011; O'Brien, 2017). *Campylobacter jejuni* can colonize in the chicken gut of without causing a disease (Newell & Fearnley, 2003) and it is shed in the feces (Humphries & Linscott, 2015). A meta-analysis of risk factors involving human campylobacteriosis shown that consumption of undercooked chicken was the major risk factor of infection secondary to international travel (Domingues, Pires, Halasa, & Hald, 2012). Other risk factors included exposure of the pathogen from the environment and direct contact with farm animals. The review of *Campylobacter* animal source attribution publication between 2010 and 2015 has revealed that chicken is the main source of attribution in Canada, Denmark, Netherlands, Scotland, and Switzerland with the proportion sources between 38% and 71% (Skarp, Hänninen, & Rautelin, 2016). Transmission of *Campylobacter* along the poultry production chain and poultry meat often occurred at farm level where farm environment contamination leads to subsequent colonization of broiler flocks (Skarp et al., 2016). Other study of genetic relatedness of *Campylobacter* in chicken production industry, from breeder flock, hatchery, broiler farm and slaughterhouse, reported that *C. jejuni* contaminated in meat products and the slaughterhouse environment had genetic relatedness to those isolated from broiler flocks than breeders (Prachantasena et al., 2016). Vertical transmission is not a main route of *Campylobacter* transmission in broiler production system. Even high variability broiler production systems, improper biosecurity, such as old condition of houses, lack of anterooms and barriers, sharing equipment between houses, long downtime, and drinker systems with bells or cups, acts as the common risk factors for *Campylobacter* colonization of broiler flocks (Sommer et al., 2016).

At slaughterhouses, higher contamination of *C. jejuni* on the carcass surface occurred when *C. jejuni*-positive flocks were processed before negative flocks (Reich, Atanassova, Haunhorst, & Klein, 2008; Miwa, Takegahara, Terai, Kato, & Takeuchi, 2003). *Campylobacter*-positive batches had significantly higher numbers of the bacteria on carcasses than those from negative batches (Hue et al., 2011). Mean number of *Campylobacter* in ceca was associated with mean number of *Campylobacter* on meat. Less fecal contamination of *Campylobacter* throughout the processing will lead to less contamination of the bacteria on the meat (Boysen, Nauta, & Rosenquist, 2016). In

addition, some subtypes survive poultry processing better than others and contaminated to slaughterhouse environment. Contamination of negative flocks during processing was proved by typing technique that the same subtypes were found in slaughterhouse environment as well as contaminated crates during transportation (Newell et al., 2001).

Prevalence of *C. jejuni* along poultry production chain and meat products varies greatly at national level. With different detection methods, sample collection sites, and types of sample collected, prevalence of *C. jejuni* in poultry was shown in Table 2.2. Quantification of *Campylobacter* was shown in Table 2.3. In addition, different of temperature between seasons was observed as a factor associated with prevalence of positive flocks (Reich et al., 2008). The higher temperature, the higher prevalence of positive flocks.

Table 2.2 Prevalence of *Campylobacter* at various sampling sites along poultry production chain by countries

Country	Year	Sampling site	Type of sample	Prevalence (%)	Reference
China	2012-2013	Slaughterhouse	Cecum[b]	34.6	(Han et al., 2016)
			Chicken carcass[b]	4.0	
Estonia	2012	Slaughterhouse	Cecum[a]	39.2	(Mäesaar et al., 2014)
		Retail market	Chicken meat[a]	20.8	
France	2008	Slaughterhouse	Pooled ceca[a]	77.2	(Hue et al., 2010)
			Chicken carcass[a]	87.5	
	2009	Retail outlet	Chicken meat[a]	49.3	(Guyard-Nicodème et al., 2015)
India	2008-2009	Pluck shop	Cecum[a]	59.5	(Parkar et al., 2013)
			Chicken carcass[a]	57.1	
Iran	2013	Retail market	Chicken meat[b]	55.6	(Zendehbad, Khayatzadeh, & Alipour, 2015)
Italy	2011-2012	Retail outlet	Ready-to-cook poultry product[a]	61.6	(Pedonese et al., 2017)
Malaysia	2008-2009	Slaughterhouse	Neck skin[a]	80.6	(Rejab, Zessin, Fries, & Patchanee, 2012)
Poland	2009-2013	Slaughterhouse	Carcass surface swab[b]	27.2	(Wieczorek & Osek, 2015)
Spain	2012	Slaughterhouse			(Torralbo et al., 2015)
		Loading dock	Cloaca[b]	32.3	
		Scalding	Whole carcass[b]	25.6	
			Scalding water[b]	24.5	
		Evisceration	Whole carcass[b]	38.8	
			Equipment[b]	40.7	
		Classified	Whole carcass[b]	37.0	
			Equipment[b]	19.7	
		Quartering	Quartered carcass[b]	33.8	
			Equipment[b]	18.7	
		Packing	Quartered carcasses/ final meat product[b]	20.5	
Thailand	2000-2003	Farm	Cloacal swab[a]	63.9	(Padungtod & Kaneene, 2005)
		Slaughterhouse	Cloacal swab[a]	35.6	
			Surface swab[a]	38.4	
		Market	Chicken meat[a]	47.2	
	2002-2003	Retail market	Chicken meat & gizzard[b]	58.0	(Saengthongpinit, Viriyarampa, & Sakpuaram, 2005)
United States	2005-2011	Retail outlet	Chicken meat[b]	27.1	(Williams & Oyarzabal, 2012)

[a] Detection of *Campylobacter* spp.
[b] Detection of *Campylobacter jejuni*

Table 2.3 *Campylobacter* enumeration of various sampling sites along poultry production chain by countries

Country	Year	Sampling site	Type of sample	*Campylobacter* counts	Reference
Cameroon	2005-2006	Slaughterhouse	Chicken neck skin[a]	3.46 log CFU/g	(Garin et al., 2012)
China	2012-2013	Retail outlet	Chicken carcass	1.76 log CFU/g	(Bai, Cui, Xu, & Li, 2014)
Estonia	2012	Retail market	Chicken meat	3.20 log CFU/g	(Mäesaar et al., 2014)
Germany (Berlin)	2003-2004	Retail outlet	Chicken leg skin	2.4 log CFU/g[b]	(Scherer, Bartelt, Sommerfeld, & Hildebrandt, 2006)
India	2008-2009	Pluck shop	Cecum	4.55 log CFU/g	(Parkar et al., 2013)
			Chicken carcass	2.69 log CFU/g	
Madagascar	2005-2006	Slaughterhouse	Chicken neck skin[a]	3.06 log CFU/g	(Garin et al., 2012)
New Caledonia	2005-2006	Slaughterhouse	Chicken neck skin[a]	3.35 log CFU/g	(Garin et al., 2012)
New Zealand	2007	Processing plant	Chicken carcass[a]	2.88 log CFU/ carcass	(Chrystal, Hargraves, Boa, & Ironside, 2008)
Senegal	2005-2006	Slaughterhouse	Chicken neck skin[a]	3.36 log CFU/g	(Garin et al., 2012)
Vietnam	2005-2006	Slaughterhouse	Chicken neck skin[a]	1.81 log CFU/g	(Garin et al., 2012)

[a] Average counts were calculated from positive samples only.

[b] Median of positive samples

2.5 Thailand broiler meat production

Thailand has become one of the world's largest agricultural products exporter or is recognized as kitchen of the world. The trend of poultry production in Thailand has been increasing over the decades due to higher demand domestically and internationally. Poultry, especially chicken, meat has been recognized as a lower-price source of protein. In 2016, Thai chicken meat production was 1,780,000 metric tons with approximately 60 percent came to domestic consumption. The production is forecast to increase 5-7 percent in 2017 (Global Agricultural Information Network, 2016). Moreover, it is forecast to be in the 9th rank of the world poultry meat production country and in the 3rd rank of the world poultry meat exporter (USDA, 2017). A ten-year trend of Thai poultry meat production, domestic consumption and exportation was shown in Figure 2.3.

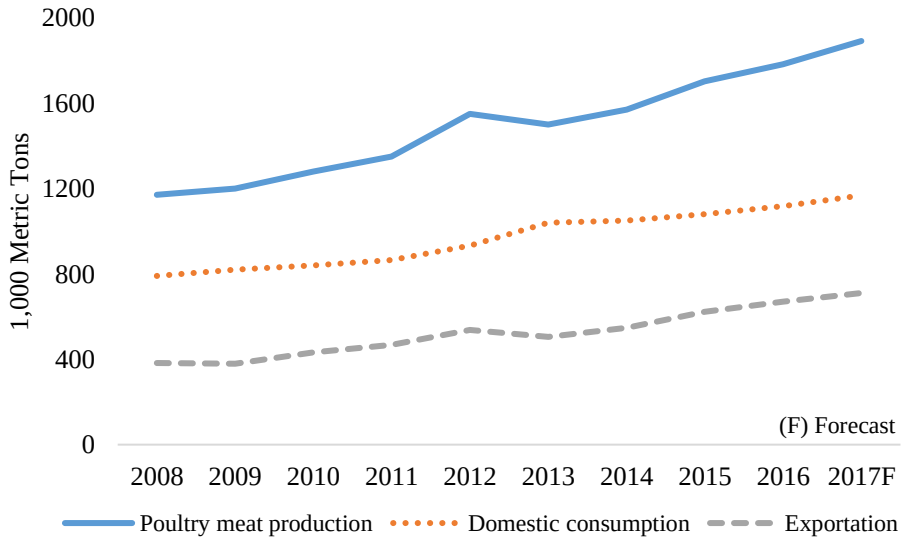

Figure 2.3 Thai poultry meat production, domestic consumption and exportation (2008-2017) (USDA, 2017)

A classification system of poultry production system described by the Food and Agriculture Organization of the United Nations (FAO) was categorized the production systems into 4 groups based on the level of biosecurity and the marketing systems of birds and products (Table 2.4).

Table 2.4 Classification of poultry production systems (FAO, 2004)

	Sector 1	Sector 2	Sector 3	Sector 4
System	Industrial and integrated	Commercial with high biosecurity	Commercial with low biosecurity	Village or backyard
Biosecurity	High	Moderate to high	Low to minimal	Minimal
Bird and product marketing	Commercial	Usually commercial	Birds usually sold in live bird markets	Birds and products consumed locally

In Thailand, most of national production (70%) was from industrial and integrated production systems (sector 1) which also play and important role in the export market while 20% of production was from commercial with high biosecurity system (sector 2). Sector 3 and 4 were the sections that have less number of production, but almost 99% of producers were in these sectors (Rushton, Viscarra, Bleich, & McLeod, 2005). Most of sector 1 has been usually dense in the Central part of Thailand, where the meat products are mainly exported and distributed to high end markets such as supermarkets. The poultry production systems in the Northern are mainly in sector 2, 3 and 4 where sector 2 supplied birds to commercial slaughterhouses and backyard slaughterhouses were supplied by sectors 3 and 4. Information of poultry production in the Upper Northern Thailand by province and broiler farms in Chiang Mai province was shown in Table 2.5 and Table 2.6. Meat products supplied to commercial slaughterhouse usually came from a closed raising system while backyard raising supplied its own type slaughterhouse.

Table 2.5 Poultry production in Upper Northern Thailand by province, 2015 (Thailand Department of Livestock Development, 2015)

Province	Native chicken	Broiler	Layer	Broiler (parent stock)	Layer (parent stock)	Total
Chiang Mai	2,482,894	1,509,613	2,967,290	9,990	127,894	7,097,681
Lamphun	1,453,171	1,858,892	641,257	296,595	93,012	4,342,927
Lampang	1,440,442	1,163,835	394,118	85,395	139,375	3,223,165
Phrae	946,743	259,240	409,812	40	10	1,615,845
Nan	1,589,016	87,415	88,617	3,873	1,656	1,770,577
Phayao	1,396,795	132,262	141,793	906	503	1,672,259
Chiang Rai	2,417,682	438,195	1,230,823	7,050	32	4,093,782
Mae Hong Son	293,255	538	20,133	50	1,378	315,354
Total	12,019,998	5,449,990	5,893,843	403,899	363,860	24,131,590

The slaughter production system defined in this study was specified by slaughter capacity (head per day). A small-scale or backyard slaughterhouse has a capacity of less than 100 head per day while the large-scale (or commercial type) has a capacity of more than 10,000 head per day. Large differences of production capability depended on investment volume and target market. The backyard slaughterhouse is the operating unit in which the owners supply meat products within or around their households, typically slaughter chickens received from small farms or their own backyard rearing for day to day consumption. Generally, customers are people who live in those areas and have less access to urban markets or supermarkets. Instead, commercial slaughterhouses generally belong to big poultry companies or have slaughter contracts with companies, resulting to the potential capability to produce and distribute poultry meat products to higher markets in Chiang Mai and other provinces in the Upper Northern region of Thailand because of higher slaughter capacity and higher broiler supply from contract farms.

Table 2.6 Type of broiler farms in Chiang Mai province (Thailand Department of Livestock Development, 2016)

List	Number of farms (%)
Total broiler farms	318 (100)
Rearing system	
Closed	285 (89.62)
Open	30 (9.43)
Closed/open	2 (0.63)
Unspecified	1 (0.31)
Farm registration with the Department of Livestock Development (DLD)	
Yes	151 (47.48)
No	167 (52.52)
Type of business	
Company's farm	17 (5.35)
Contract raiser	201 (63.21)
Contract farming	70 (22.01)
Independent raiser	19 (5.97)
Others (unspecified)	11 (3.46)
Farm size	
Small (<5,000 birds)	12 (3.77)
Medium (5,000-10,000 birds)	161 (50.63)
Large (>10,000 birds)	145 (45.60)