White Paper on Human Illness Caused by *Campylobacter* spp. from all Food and Non-Food Vectors

M. Ellin Doyle
Food Research Institute,
University of Wisconsin-Madison, Madison WI 53706

INTRODUCTION

Campylobacter spp. are microaerophilic, Gram negative bacteria that were first isolated in the early 1900s from the tissues of aborting sheep and were later detected in some farm animals with diarrhea. Campylobacters are generally more sensitive to environmental conditions than other foodborne bacteria including *Salmonella*. In the 1970s, they were recognized as a cause of human illness, with *C. jejuni* being the species most frequently described as affecting humans. *C. jejuni* is now one of the most common bacterial causes of human foodborne illness.

Campylobacter spp. usually cause mild to moderate gastrointestinal symptoms in humans. However, some infections involve more severe or prolonged diarrhea and may result in chronic long-term effects or sequelae, such as reactive arthritis and Guillain-Barré syndrome (a neurological disorder) which can significantly increase disability and treatment costs.

Numerous wild and domestic animals harbor campylobacters, often without exhibiting any symptoms. Natural habitat of these bacteria appears to be the gastrointestinal tract of a wide variety of animals, including livestock, companion animals, and many wild animals such as birds, mammals, and reptiles. Poultry, in particular, are reported to frequently harbor *Campylobacter* spp. With the exception of abortions in sheep and other ruminants and some enteritis in swine and young animals, campylobacters do not generally cause significant illness in animals. However, animal wastes containing *Campylobacter* can contaminate drinking water and plants in the environment and animals themselves may be a source of infection to humans who handle them.

Foodborne campylobacteriosis is primarily associated with milk and meat, particularly poultry, although there have also been outbreaks associated with fresh produce and seafood. Unlike *Salmonella*, *Campylobacter* does not grow on meat. Some very large outbreaks occurred when drinking water supplies were contaminated. In many countries, the number of cases of foodborne *Campylobacter*iosis now approaches or exceeds the number of cases of salmonellosis.

EPIDEMIOLOGY OF *CAMPYLOBACTER* SPP.

Important species of *Campylobacter*

Campylobacters isolated from livestock were first assigned to the genus *Vibrio* and then in the 1960s were reclassified as the genus, *Campylobacter*. (27) In fact, the first reported outbreak, believed to be caused by *Campylobacter*, occurred in 1938 and was attributed to *Vibrio jejuni* in raw milk (157).

C. jejuni is the species most often associated with human gastrointestinal illness. Analyses of >21,000 *C. jejuni* isolates from cases of diarrhea around the world revealed that 8 serotypes account for more than 50% of sporadic cases and three strains (HS4 complex, HS2, and HS1/44) appeared to be particularly important (204). A virulent, tetracycline-resistant strain of *C. jejuni* (SA) has emerged in ruminants in the U.S. and has been found to match about 9% of

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the human *C. jejuni* isolates in the CDC PulseNet database. These isolates came from sporadic and outbreak-related cases, with most of the outbreaks attributed to raw milk (223).

During the past decade, advances in molecular methods and development of new procedures for culturing fastidious strains of *Campylobacter* have demonstrated that several other species can cause gastrointestinal symptoms or periodontal disease in humans: *C. coli*, *C. fetus, C. lari, C. concisus*, *C. upsaliensis*, and *C. ureolyticus* (39, 57, 134, 168, 189, 201). Multiple species of *Campylobacter* were recently detected in swine cecal contents, with *C. concisus* determined to be the second most common species (230). *C. ureolyticus* was detected in humans with diarrhea, in bovine feces and unpasteurized milk as well as in dog and cat feces in surveys in Ireland (144, 145). Many *Campylobacter* species are difficult to grow in culture and laboratories do not always determine the species of *Campylobacter* detected in clinical specimens. So the true distribution and incidence of illness caused by different species is not really known.

Multilocus sequence typing (MLST) uses information on the genetic sequence of 7 housekeeping genes in bacterial isolates to assess their similarity to other strains of the same species or genus. A total of 7992 MLST sequences of strains of ten *Campylobacter* species (*jejuni, coli, upsaliensis, concisus/curvus, hyointestinalis, lanienae, insulaenigrae, lari, sputorum*, *helveticus*) have been entered into the public MLST website as of November, 2014 (53, 131). These data are useful in classifying new isolates.

Antibiotic Resistance in *Campylobacter* spp.

Antibiotic resistance, including multi-drug resistance, is an increasing problem globally. Data from the most recent USDA-NARMS report on antibiotic resistant bacteria in farm animals indicated that about 20-27% of *Campylobacter* isolates from chickens in 2011 were resistant to quinolines and 42-45% were resistant to tetracyclines. About 1.3% of isolates were multi-drug resistant. (186) Data from Europe reported that the proportions of multidrug resistant *Campylobacter* in broilers in 2012 were 22.5% (*C. coli*) and 1.6% (*C. jejuni*); For pig isolates, the proportion was 34.6% (*C. coli*) and for cattle, 12.3% (*C. jejuni*). These numbers are averages for European Union countries; in some countries the percentages are significantly higher than in others. (77) A recent publication by CDC on antibiotic resistance threats in the U.S. listed drug-resistant foodborne bacteria, including *Campylobacter*, as serious health threats. (206) Significant levels of antimicrobial resistance have been reported in *Campylobacter* isolates from meat and livestock:

- Retail chicken liver in the U.S. (amoxicillin, oxytetracycline, cephalothin) (192)
- Retail chicken and turkey in Canada (ciprofloxacin) (5, 54)
- Pigs and chickens with multidrug resistance in Brazil (29, 60)
- Broilers, cattle and pigs in Japan (enrofloxacin) 109)
- Turkeys with multidrug resistance in Germany (70)
- Pigs in China (ciprofloxacin, clindamycin, erythromycin, tetracycline) (208)
- Poultry in China resistant to organic arsenic (roxarsone) (240)

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Numerous other articles in the scientific literature demonstrate the global nature of this problem with resistance to antibiotics, some of which are important for treating human infections, reported from many countries in Africa, Asia, Europe and South America.

Overuse and misuse of antimicrobials in human and veterinary medicine are believed to be the driving force that increases selective pressure for evolution of more drug-resistant strains. Some evidence from recent studies of *Campylobacter* in livestock includes:

- Experiments in Japan demonstrated that 3-4 days after dosing pigs with fluoroquinolones, resistant *Campylobacter* could be detected in animal feces. These bacteria persisted for 21 days after stopping the drug treatment. Other experiments showed that fluoroquinolone-resistant *Campylobacter* could be readily passed from one pig to others when they were housed in one pen (266).
- In Canada, treatment of feedlot cattle upon arrival with tetracyclines was found to increase the proportion of tetracycline-resistant *Campylobacter* during the feedlot period (124).
- A study of dairy cattle raised on organic and conventional farms in Midwestern U.S. found antibiotic resistant *Campylobacter* in animals from both farms. However a higher proportion of bacteria from the conventional farms exhibited antibiotic resistance (104).
- Since 2003, the predominant *C. jejuni* isolate causing abortions in U.S. sheep has been a highly pathogenic, tetracycline-resistant strain called SA (ST-8). Tetracyclines are commonly used in the U.S. to prevent abortions. In contrast, in Great Britain where tetracyclines are not commonly used for this purpose, *C. jejuni* isolates associated with ovine abortions were susceptible to most antibiotic tested (283).

Human Illness

Campylobacter spp. are estimated to cause about 845,024 cases of foodborne illness annually in the U.S. (229) and FoodNet data from 2013 indicate an incidence of 13.82 cases of campylobacteriosis/100,000 people. During the past ten years, incidence has ranged from 12.64 (2008) to 14.28 (2011), without a noticeable consistent decline in incidence. The number of foodborne outbreaks of campylobacteriosis, reported to CDC, increased from 15 in 2009 to 37 in 2012 (47). There is still work to be done to achieve the 2010 National Health Objective of 12.3 and the 2020 objective of 8.5 cases/100,000. (56)

Campylobacter spp. ranks either first or second (behind *Salmonella* spp.) in bacterial causes of human gastroenteritis in Europe, Canada, Australia and New Zealand. (69, 99, 161, 259) The European Union reported an overall notification rate of 55.49/100,000 population in 2012. Incidence varies from country to country; in some cases this is because national public health surveillance systems vary in their effectiveness. Significant increasing trends in campylobacteriosis were observed in 15 countries. Few people died from *Campylobacter* infections, with a calculated case-fatality ratio of 0.03%. (69) In 2013, Foodnet Canada reported an incidence rate of 29.5 cases/100,000 population (42) and Australia reported an incidence rate of 95.3 cases of campylobacteriosis/100,000 population (114).

Campylobacter causes symptoms of gastroenteritis that are commonly mild to moderate and infectious dose appears to be relatively low – about 500 cells or less. (106, 143, 215) Data

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from outbreaks in which all cases were exposed to contaminated food or water during a short period of time (<24 hours) indicated that 84% of cases experienced symptoms within 4 days of exposure and only 1% had an incubation period lasting 8 days (119). Economic costs for most cases of human Campylobacteriosis, that do not involve chronic sequelae, are usually relatively low. However, the large number of cases that occur are estimated to cost annually a total of >$1.5 billion in the U.S. (118, 232)

Early on, it was noted that some patients recovering from gastrointestinal illness suffered long term sequelae such as reactive arthritis (36, 67) and Guillain-Barre syndrome (GBS) (10). In fact, sometimes a cluster of cases of GBS is an indication the there has been a recent outbreak of campylobacteriosis. This was the case in 2011 when a binational outbreak of GBS in Arizona and Mexico in 2011 was found to be associated with a large outbreak of *C. jejuni* caused by inadequately disinfected water in Mexico. (126) It appears that persons suffering more severe or prolonged gastrointestinal symptoms are more likely to develop GBS or reactive arthritis (163, 234)

GBS is an acute neurological disorder that first affects peripheral nerves causing numbness and tingling in hands and feet and weakness in muscles of the arms and legs. Most people recover after several months. But in some cases, the disease progresses to affect muscles controlling breathing and heart rate and may have serious consequences. *Campylobacter* infections are one of the primary triggers causing this disease because some lipo-oligosaccharide structures on the bacterial cell surface are very similar to ganglioside molecules on nerve surfaces. Therefore, in attempting to fight off the *Campylobacter* infection, the body produces antibodies that also attack its own nerves. More recent studies of GBS cases in several countries have utilized molecular and serological methods, involving isolation and testing of antibodies from GBS patients for cross reactivity with *Campylobacter,* to demonstrate the connection between this foodborne infection and neurological disease. One study indicated that 34-49% of GBS cases had evidence of previous *Campylobacter* infection (125, 289, 292).

Reactive arthritis is another long-term effect of some food poisoning episodes (7, 261). It has been reported that the incidence of reactive arthritis following *Campylobacter* and *Salmonella* infections were 2.1 and 1.4/100,000, respectively. (262) One study found that 44-62% of cases of reactive arthritis had serological evidence of a previous *Campylobacter* infection. (289) Following a large waterborne outbreak of *Campylobacter*iosis in Finland in 2007, 7% of the exposed population reported newly developed arthritis-like symptoms. These symptoms persisted longer than gastroenteritis and some persons reported continuing joint pain 15 months later (151).

Normal gut flora in individuals appears to affect susceptibility to *Campylobacter* infection. Poultry abattoir workers with a significantly higher abundance of *Bacteroides* in their gut microbiota were more likely to become culture positive when exposed to *Campylobacter* than those with lower proportions of *Bacteroides*. In addition, infection/colonization of workers with *Campylobacter* significantly altered the composition of their intestinal microbiota (63). Such alterations in microbiota may, in turn, be a possible mechanism for development of chronic gastrointestinal symptoms (251). Campylobacters are suspected of playing a role in the development of some chronic gastrointestinal conditions. There are indications that more severe gastrointestinal symptoms during campylobacteriosis may be a factor in development of inflammatory bowel disease (289), irritable bowel syndrome (190) and celiac disease (214) in some individuals.

Outbreaks and cases

Data on outbreaks tabulated by CDC (1998 – 2012) indicate that dairy products were responsible for about 50% of outbreaks with a known or suspected vehicle and poultry was responsible for another 19%. (47) Raw milk continues to be a source of infection in the U.S. (183) and the most recent outbreak in 2014 in WI, affected 38 people who consumed raw milk served at a dinner for a high school football team. (24) Another recently recognized vehicle is liver paté, which has caused numerous small outbreaks in the UK and other countries in recent years. Since liver becomes tough when overcooked, some chefs only lightly cook liver thereby permitting the survival of *Campylobacter*. (81) Although *Campylobacter* spp. are sensitive to stomach acid, the presence of food and liquids in the diet may offer some protection until the bacteria reach the relative safety of the small intestine.

Table 1 lists some of the large foodborne *Campylobacter* outbreaks that have been reported in the past 15 years and Table 2 lists some large drinking water outbreaks. Overall waterborne outbreaks account for about 17% of reported outbreaks with a known cause. However, in terms of cases, contaminated water caused nearly 75% of cases because many waterborne outbreaks involve hundreds or thousands of cases. (Figure 1) A total of 504 outbreaks affecting 57,221 people were described in the scientific literature and have been compiled in the Appendix to this paper.

For strictly foodborne outbreaks and cases, milk accounts for a very large percentage of outbreaks and cases. Meat also accounts for about a third of outbreaks and 18 % of cases. (Figure 2). Chicken is associated with a majority of meat-related outbreaks and cases. From data gathered for this paper, pork appears to be a major cause of campylobacteriosis but this is due to one large Japanese outbreak affecting about 800 people. (Figure 3) Relatively few outbreaks are caused by fresh produce, fish, animal contact, and person to person transfer, although all of these types of outbreaks have occurred.

As with other foodborne pathogens, epidemiologists estimate that many more sporadic cases than reported outbreak cases of campylobacteriosis occur. (217) A multiplier of 30.3 has been used to account for underdiagnosis in order to estimate the actual number of cases of campylobacteriosis in the USA. (229) It is not clear whether the same vehicles of infection are causing sporadic cases in approximately the same proportions. Studies in different countries have implicated several different vehicles but results of these studies are not necessarily comparable because different questions were asked and different definitions used (86). Risk factors for campylobacteriosis undoubtedly vary somewhat by age because of differences in occupational and leisure time activities and consumption of different foods (46, 62). Risks likely also vary somewhat geographically. Among the risk factors identified as associated with sporadic campylobacteriosis are: drinking well water or surface waters as compared to ground water (46, 195, 264), consumption of chicken or other meat (46, 80, 88, 187, 265), consumption of restaurant food (62, 88, 265), and poor kitchen hygiene probably resulting in cross-contamination (62, 88).

Reservoirs of *Campylobacter*

Livestock

Cattle. *Campylobacter* is commonly detected in fecal material from cattle. Analysis of manure samples from broilers and cattle, in 2013, by the Public Health Agency of Canada revealed that *Campylobacter* was present in about 75% of dairy and beef cattle manure (42) Some recent surveys reported incidences of *Campylobacter* in fecal samples of: about 50% of dairy cattle in Finland (103), 42% of dairy cows in Japan (228), 28% of dairy cattle in Canada (101), 15% of calves in Austria (142), and 19% of cattle in South Africa (263). Several studies examining factors related to *Campylobacter* among dairy cattle reported that inadequate biosecurity measures, indoor housing (as in winter), larger herd size, and infrequent cleaning of water troughs were associated with a higher incidence of *Campylobacter* (71, 101, 142, 210). Some bacterial strains persist for a long time in cattle herds and appear to be adapted for life in cattle (149).

Small ruminants. Both sheep and goats may harbor *Campylobacter*, but goats appear to be colonized less frequently (155, 198). However, in some locations, *Campylobacter* may be present in a significant number of goats and in meat derived from them (181). *Campylobacter* strains detected in grazing small ruminants in the U.S. differed from those detected in wild birds in the same environment (198).

Campylobacter, particularly, *C. fetus*, is a well-known cause of abortions in sheep. Vaccination of sheep with antigens from *C. fetus* does protect pregnant sheep from this species (169). *Campylobacter* spp. can be present in sheep fecal samples and may also be isolated from gall bladders of adult sheep. (75)

Poultry. *Campylobacter* is generally considered a commensal organism in poultry, i. e. it exerts no harmful effects on the birds. However, some recent research indicates that different breeds of chickens react differently to *Campylobacter* colonization and in some breeds there is a long inflammatory response, damage to the gut lining and diarrhea (122).

Reports of the prevalence of *Campylobacter* in poultry vary by country because of different surveillance procedures and husbandry practices as well as geographical and climatic differences. Generally, *Campylobacter* isolations peak in Summer and Fall and decline during Winter (50, 109, 277). A wide range in the incidence of *Campylobacter* in broilers was reported from European countries from 1.6% of animals tested (Finland) to 83.6% of animals (Hungary). While results are not strictly comparable between countries because of differences in sampling programs, the four countries with *Campylobacter* control and surveillance programs reported low to moderate levels of *Campylobacter* (1.6 – 11.6%). (68)

According to the USDA quarterly report (Jan - Mar 2014) on *Campylobacter* in poultry, 1.6% of 367 turkeys and 5.9% of 1415 young chickens harbored *Campylobacter* (238). Manure samples from broilers and turkeys, collected in 2013 by the Public Health Agency of Canada,

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revealed that *Campylobacter* was present in 20 – 28% of broiler manure and about 80% of turkey manure (42). Surveys conducted at poultry slaughterhouses in Canada found *Campylobacter* in 35.8% of chickens (16) and 36.9% of turkeys (17). Reports from other countries indicate that *Campylobacter* was detected in:

- 35% of chickens on farms in South Africa (263),
- 42.7% of flocks tested in Japan (109)
- 60% of breeding hens in Argentina (290)
- 76.1% of broiler flocks, 90% of turkey flocks, 68.2% of Muscovy duck flocks, and 59% of Pekin duck flocks kept on the same farms in Germany (277)
- 75.6% of chickens at wet markets in Malaysia (170)
- 38% of chickens and 62.9% of poultry flocks in Spain (260)

Origins of infection in poultry have been investigated by several researchers. Chicks start shedding *Campylobacter* in feces at around 4 weeks of age, although they may harbor these bacteria in their ceca before they start shedding (94, 285). *Campylobacter* may be ingested on particles of dust, food or feces by poultry. *Campylobacter* concentrations in feces of colonized birds may be as high as 10^8 cfu/g and may remain viable for 5-6 days after deposition (6). Drinking water that has not been disinfected was identified as a likely source of infection for chicks (109, 260). Other animals on a farm may also be a source or, in the case of rodents for example, may spread *Campylobacter* around the farm environment (260). A study in Switzerland found that similar *Campylobacter* strains were present in poultry, pigs and cattle living on the same farm. Some strains were observed first in poultry and then in other livestock while other strains were isolated first from other livestock (294). Thinning of flocks also appears to increase *Campylobacter* colonization in flocks (94, 260).

Although multiple *Campylobacter* strains are often detected in poultry (105, 242), it appears that certain strains may be better adapted for survival in chicken gastrointestinal tracts (18).

Swine. Pigs commonly harbor *Campylobacter* spp., usually *C. coli*, often without becoming ill. However, *C. coli* and *C. jejuni* have been the only pathogens detected in some swine with diarrhea (41). Piglets may be colonized during the first week of life, often from contact with their mothers, and prevalence of *Campylobacter* usually increases during life so that at the finishing stage, the majority of pigs harbor *Campylobacter*. At slaughter, a large percentage of pigs carry *C. coli* in their digestive tracts and, to a lesser extent, in their tonsils (21). A recent examination of fastidious campylobacters in swine cecal contents found a wide range of species and found that *C. concisus* was the second most common species (230). When chlortetracycline was fed to pigs, it was reported to decrease numbers of *Campylobacter*, but not pathogenic *E. coli* in fecal samples (280).

Other farmed animals. *Campylobacter* spp. have occasionally been reported from other animals raised on farms.

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- Rabbits in Italy and Portugal were reported to commonly harbor a new thermophilic *Campylobacter*, *C. cuniculorum*. *C. jejuni* and *C. coli* were detected in only a few animals (212).
- *Campylobacter* spp. were detected on about 10% of ostrich carcasses sampled at slaughterhouses in Ohio and Indiana (159).
- *Campylobacter* spp. were detected in 80% of ducks sampled in Tanzania (191) and in 12 % of ducks tested in Malaysia (79).
- Assays of 500 fecal samples from farmed camels in Saudi Arabia revealed the presence of *Campylobacter* spp. in about 5% of them. Most were identified as *C. jejuni*, with a few isolates of *C. coli* and *C. lari* (9).
- *Campylobacter* has been reported to cause abortions in farmed alpacas in England (30) and in mink on Canadian ranches (123).

Companion Animals

Dogs. Of all companion animals, dogs appear to be the most important reservoir for *Campylobacter* spp. Research has demonstrated that the same or very similar strains of *Campylobacter* are present in dogs and humans. (182, 253) Ownership of dogs is one of several risk factors for *Campylobacter* infection in humans (246) and one study attributed about 8.6% of sporadic human campylobacteriosis to contact with dogs (138). A human outbreak of *Campylobacter* enteritis was associated with dogs. (137)

Surveys in Australia, Canada, Chile, India, Iran, Ireland, Slovakia and Spain reported that 30-50% of healthy dogs carried *Campylobacter* and excreted the bacterial cells in their feces (1, 20, 23, 44, 48, 82, 207, 269). Prevalence of *Campylobacter* in healthy Swiss dogs was reported to be only 6.3%. (11) The most common species identified in these surveys were *C. upsaliensis* and *C. jejuni*, with smaller numbers of *C. coli*.

Campylobacter shedding is more frequent in summer and is more common in puppies and old dogs, in dogs at shelters, and in dogs with access to ponds and lakes. (1, 23, 44, 82, 207) Some *Campylobacter* strains appear to cause diarrhea in dogs. (11)

Cats and other mammals. Healthy cats in Minnesota were found to harbor *C. upsaliensis*, *C. jejuni*, and *C. coli* with an overall *Campylobacter* prevalence of 24%. As with dogs, *Campylobacter* was more frequently isolated from young cats, less than one year old. (28) *C. ureolyticus*, an important cause of human gastroenteritis, has been detected in 32% of cat fecal samples in Ireland, as well as in dog feces (144). Surveys of cats in The Netherlands (182), Norway (224), Iran (48), and Poland (13) also reported that these animals carry *Campylobacter* spp. The Polish cats had been in contact with poultry or wild birds.

Campylobacter has occasionally been isolated from horses. (294) *Campylobacter* spp. and *E. coli* were identified as probable causes of diarrhea and enterocolitis in a hamster colony suggesting that small mammal pets may also be a source of human infection. (64)

Birds. A study of “hobby” birds in Denmark in 2000-2001 detected *Campylobacter* in 4% of parrots and canaries, 11% of racing pigeons, and 77% of hens and peacocks. (278) A recent review of zoonoses associated with pet birds (33) indicated that *Campylobacter* can be shed by asymptomatic canaries, parakeets, and parrots. However, the strains isolated from these birds appear to be host specific and may not pose a risk to human health.

Reptiles. Although few surveys of *Campylobacter* in reptiles have been published, it appears that this group of animals is not a major reservoir of *Campylobacter*. Only 6.7% of human-raised reptiles (turtles, lizards, snakes) in Taiwan tested positive for *Campylobacter* and all isolates were identified as *C. fetus* strains that differed from most mammalian *C. fetus* strains. (276) Only eight of 109 captive reptiles in Italy tested positive for *C. fetus* or *C. hyointestinalis*. (92) These species are rarely detected in humans and may not pose a risk to pet owners. No *Campylobacter* spp. were detected in 200 pond turtles in Spain although many turtles did harbor *Salmonella* (171).

Wild Animals

Campylobacter spp. are also present in many wild animals although their public health significance is unclear. Rodents, insects, and birds may disperse *Campylobacter* in the environment and colonized game animals may pose some risk to hunters. Wild non-human primates may also harbor *Campylobacter* and may also pose a risk to hunters and to researchers who work with these animals. (188, 202)

Surveys have demonstrated the presence of *Campylobacter* in rodents on farms (2, 19) and those living in human facilities (164). Squirrels have also tested positive for these bacteria (65). Among larger game animals, *Campylobacter* is more frequently detected in wild boar/feral swine than in deer (43, 127, 225).

Birds have apparently played a role in some outbreaks of human *Campylobacter*iosis. In the late 1980s in England, jackdaws and magpies pecked at the tops of milk bottles left outside houses and introduced *Campylobacter* into the pasteurized milk, causing human illness (121), An outbreak of campylobacteriosis in Alaska in 2008 was traced to consumption of raw peas apparently contaminated by sandhill cranes that frequented the farm fields. *C. jejuni* was detected in crane feces (148). However, it appears that many *Campylobacter* strains carried by birds are distinct from those present in other species (97). An infection experiment demonstrated that European robins could be colonized by *Campylobacter* isolates from related birds but not by *Campylobacter* isolates from humans (275).

Numerous surveys reported detection of *Campylobacter* spp. in birds, including:

- 9.2% of wild ducks and gulls in mid-Atlantic U.S. (136)
- 5-16% of urban geese in North Carolina (220)
- 7% of wild raptors in Spain (178)
- penguins in Antarctica (98)
- 67% of crows in California (279)

Numerous insects live on farms and may contribute to the spread of pathogenic organisms to various environmental surfaces and among the many animals living there. *Campylobacter* has been isolated from flies on dairy farms (2), poultry farms (49), and pig farms

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(185). Contaminated insects may also be eaten by livestock. Broilers fed darkling beetles contaminated with *Campylobacter* were colonized with the bacteria. (113)

Routes or Vehicles of Human Infection

Contaminated food and water

Food containing *Campylobacter* spp. is one of the main sources of human campylobacteriosis. Such food may be consumed directly, either raw or lightly cooked, and may cross contaminate other foods, such as salad ingredients, during food preparation.

Campylobacter was also present on the external packaging of retail raw meat during a study in the UK. Contamination was less frequently observed when packaging was intact, display areas were visually clean, and display temperatures were <8ºC. (40)

Dairy products. Milk, particularly raw milk, is the most common vehicle identified as the cause of outbreaks of *Campylobacter*iosis. (See Figure 1.) An increasing number of outbreaks associated with raw milk have occurred in the USA from 2007 to 2012. (183) Milk may be contaminated by fecal material on the udder or lapses in hygiene control during milking. Direct excretion of *Campylobacter* into milk by cows has also been documented (197)

Several studies have documented the presence of *Campylobacter* in raw bulk tank milk. Reported prevalence varies, including:

- 0% of tanks from 183 Finnish farms and 310 from Swiss farms, although some samples did contain *L. monocytogenes* or *E. coli* O157:H7. (221, 248)
- 9.2% of 131 tanks from MN and SD (129)
- 2% of tanks in PA (128)

Campylobacter spp. was detected in 16 of 49 inline milk filters from 14 farms in Italy authorized to sell raw milk. *Arcobacter* spp. was detected in 36 filters. (237)

Monitoring of over 60,000 containers of raw milk sold in vending machines in Italy during 2008-2011 revealed the presence of bacterial pathogens (*Listeria monocytogenes*, *Salmonella*, *Campylobacter*, and *E. coli* O157:H7) in 0.3% of raw milk samples. *Campylobacter* spp.was detected in 30% of the positive samples. (93)

Of reported sporadic enteric infections occurring in people who consumed raw milk in MN in 2001-2010, 77% (407 cases) were caused by *Campylobacter*. Using a multiplier to account for underdiagnosis, it was estimated that the actual number of cases exceeded 12,000. In contrast only 15 outbreak-related cases of campylobacteriosis were associated with raw milk during this period. Even if some of the sporadic cases were not caused by exposure to raw milk, these data indicate that the number of sporadic cases, due to *Campylobacter* in raw milk, greatly exceeds the number of outbreak cases. (217)

Fermented dairy products and butter are not as good media for survival of *Campylobacter* because of the presence of organic acids in the former and lack of water in the latter. However, an outbreak in 1995 was attributed to *C. jejuni* in garlic butter and subsequent investigations found that *C. jejuni* could survive in plain butter for less than 3 days at 21ºC and for at least 13 days at 5ºC. These bacteria died within several hours at both temperatures if garlic were present

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(293). Traditional cheeses and butter, as well as raw milk in Iran were found to be contaminated with *Campylobacter*. (209)

Chicken. Poultry is commonly contaminated with *Campylobacter* and is often implicated as a vehicle for human Campylobacteriosis. In the previous section on animal reservoirs of *Campylobacter*, data were presented on the presence of *Campylobacter* in live animals and in animals just after slaughter. This section considers contamination of poultry meat during processing of animals in slaughterhouses and in meat sold in retail establishments.

USDA quarterly report (Jan - Mar 2014) on *Campylobacter* in poultry found that 0.88% of turkey meat and 10.77% of chicken meat were contaminated with *Campylobacter*. Mechanically separated chicken and turkey were 5 – 10 times more contaminated than ground or other comminuted meat (238). Analyses of retail chicken breasts and ground chicken, in 2013, by the Public Health Agency of Canada, detected *Campylobacter* in 44-46% and 17%, respectively (42). Data from the second quarter of a year long (2014-2015) survey of *Campylobacter* in retail whole chickens in the UK indicated that 70% of birds were contaminated, with 18% containing >1000 cfu *Campylobacter*/g. In addition, *Campylobacter* was detected on the outside of 6% of packages of chicken. (3).

Wide variations in contamination of chicken meat with *Campylobacter* have been reported from surveys in different countries. This is most likely due to differences in types of meat sampled (e.g. whole chickens, giblets, breast muscle, meat with skin, meat without skin), in sampling and culture methods, and in seasons when samples were collected. Some percentages of positive results from surveys published in the past 5 years are listed below:

- 67% of retail livers and gizzards in the USA (192)
- 90% of whole chickens from farmers' markets in PA; 28% of whole organic chickens and 52% of whole conventional chickens from supermarkets (233)
- 42.8% of retail poultry in Canada (45)
- 81% of retail poultry liver in the UK (249).
- 38.4% of retail chicken in Switzerland (25)
- 54.2% of organic and 19.7% of non-organic chicken carcasses at the end of processing and chilling in Denmark (219)
- 20.8% of retail chicken in Estonia (167)
- 49.7% of chicken, turkey, quail, and partridge meat in Iran (291)

Fate of *Campylobacter* present in live poultry has been traced through the slaughtering process. Identical *Campylobacter* clones were detected in chickens at farms, on carcasses during individual steps during processing and in final packaged cuts of meat ready for retail sale (160, 175). For flocks known to carry *Campylobacter*, some reductions in numbers of bacteria were seen after certain points in the processing line, but significant numbers were still present at the end of processing. Even carcasses from flocks that had tested negative for *Campylobacter* contained *Campylobacter* by the end of processing. This indicates that the abattoir environment itself harbors *Campylobacter* that can contaminate carcasses during processing. (74)

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Campylobacter- negative flocks processed at a slaughterhouse after a *Campylobacter*-positive flock can acquire the same strains of bacteria as were present in the positive flock (226).

Campylobacter on raw poultry may pose a direct risk to human health if the chicken is not cooked properly. It may also serve as a source for cross-contaminating other foods and equipment in the kitchen. In nearly 30% of trials *Campylobacter* from raw chicken was transferred to a polyethylene cutting board and then to cooked chicken placed on the contaminated board (102). In another study, transfer rates of *Campylobacter* on raw chicken to hands and kitchen equipment were measured. Rates of transfer from chicken legs and filets to hands were 2.9 and 3.8%, respectively. Transfer from filets to wooden cutting board and knife was about 1.1% and from legs to plate was 0.3%. Transfer from the plate to fried sausage was 27.5% and from knife and cutting board to raw cucumber was 10% (166). This research quantifies the significant risk for cross-contamination from raw chicken during food preparation.

According to a recent review, data from published studies on the potential for biofilm formation by *C. jejuni* indicate that this bacterium is not very proficient at forming biofilms by itself. Rather, it may persist in food-related environments by attaching to biofilms formed by other bacteria. (255) However, chicken meat exudate was found to enhance attachment and biofilm formation by *C. jejuni* on glass, stainless steel and polystyrene. It appears that particles in this chicken juice attach to abiotic surfaces and this may allow attachment and increase survival of *C. jejuni* in kitchens and processing plants (37) Rinsate of broiler carcasses, containing 10^4 – 10^5 cfu *Campylobacter*/ml was stored for up to 24 months at refrigeration or freezer temperatures. *Campylobacter* could be cultured after enrichment for up to 4 months from samples stored at 4ºC and for up to 20 months in samples stored at -23ºC. It appears that, although most of the bacteria were killed during cold storage, sublethally injured bacteria could be resuscitated after 4-20 months. (55)

Turkey. A survey of 465 packages of retail raw turkey in Canada revealed that 46% contained *Campylobacter* (54)

Beef. Analyses of 1185 samples of beef purchased in retail stores in 38 cities in the USA detected *Campylobacter* in 7.35% of ground beef packages and in 17.24% of whole muscle beef. This was significantly higher than *Salmonella* incidence (1% or less) in the same packages of meat (271). Another survey of retail beef in the Tulsa OK area found that 78% of beef liver samples contained *Campylobacter* while none of 47 packages of other beef cuts were contaminated (193). In the UK, 69% of retail bovine liver contained *Campylobacter* (249). No *Campylobacter* could be cultured from 175 samples of ground beef from Finland although 1 sample tested positive by PCR (162).

Pork. A survey of retail pork in the Tulsa OK area found that 2% of 100 samples contained *Campylobacter* (193). Swine livers collected at slaughter were reported to be contaminated with *Campylobacter* at a rate of 17.3% in Japan (227) and 10% in Germany (273). In the UK, 79% of retail pig livers were contaminated with *Campylobacter* (249). *C. coli* on raw porcine liver slices was found to survive up to 4 days at 4-37ºC but no growth occurred at any temperature. (180) Another survey found that 15% of retail pork products in Ireland contained *Campylobacter* (230).

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Mutton, Lamb. *Campylobacter* is not commonly present on lamb or mutton muscle. It was detected on only 0.3% of lamb carcasses in the U.S. (66) and on 3% of sheep carcasses in Italy (31). A survey in Australia detected *Campylobacter* on only 1 of sample of lamb and sheep legs (203). However, a survey in Greece found *Campylobacter* on 44% of liver and 32% of meat samples from lambs and goat kids (154). In the UK, 78% of retail sheep livers were contaminated with *Campylobacter* (249).

Produce. *Campylobacter* spp. is present on fresh produce from the field but prevalence appears to be quite variable. Examination of fresh vegetables at Canadian farmers' markets found that six types of vegetables, including leafy greens, radishes and potatoes, were contaminated with *Campylobacter* spp. *C. jejuni* was the most commonly detected species. (199) In over 1800 samples of fresh retail produce tested in The Netherlands, only 3 (lettuce, endive) were contaminated with *Campylobacter* (281) *Campylobacter* was detected on raw parsley but not on many other retail produce items during a survey in Mexico (95)

Survival of *Campylobacter* on fresh produce varies with type of produce and whether the plant part is above or below ground. *Campylobacter* survived significantly longer on strawberries than on carrots, cucumber and cantaloupe (135). *C. jejuni* could survive and be cultured for at least 23 days after inoculation on radish and spinach roots kept at 10ºC but declined more rapidly on spinach leaves, lasting for only 6 days. Higher temperatures decreased longevity while damage to leaves increased survival. (34)

Fresh produce can also be contaminated by cross- contamination in restaurant or home kitchens where meat is also being prepared. Recurring cross-contamination of salads occurred in an Austrian kebab shop and was attributed to poor kitchen hygiene (172)
Risk assessment for human campylobacteriosis from salad vegetables prepared in a kitchen alongside broiler meat was associated with frequency of washing hands and cutting boards and the preparation of raw poultry before salads using the same cutting board. (241)

Seafood. In contrast to pork and chicken, some seafood is traditionally consumed raw. Several outbreaks have been traced to consumption of raw clams, oysters, salmon, and tuna (47). Shellfish are filter feeders and may accumulate bacteria from surrounding sea water. Since they often live near shore, they may be exposed to runoff of animal and human wastes.

Eggs. Although chickens commonly harbor *Campylobacter*, eggs are not a common vehicle for campylobacteriosis, having been implicated only in a single 1982 outbreak in MN. When commercial eggs were surface contaminated with a fecal suspension containing *C. jejuni*, the bacteria were detected inside of only 1 of 70 eggs. *Campylobacter* remained viable on the shell surface for a maximum of 16 hours. Furthermore, hens known to shed *C. jejuni* did not produce contaminated eggs. (239)

Water. Several large outbreaks of campylobacteriosis have been traced to contamination of public drinking water. Causes have been identified as cracks in aging pipes and water storage facilities, cross connections between drinking water pipes and sewage or non-potable water pipes, contamination of wells or reservoirs by surface runoff following heavy rains or rapid snow melt, or failure of water treatment, usually chlorination. (See Table 2 for examples.) Waterborne disease outbreaks occurring in developed countries during the past 30 years were reviewed to determine why these outbreaks keep occurring even when we know how to prevent them (120). An epidemiological study of sporadic campylobacteriosis in British Columbia reported that use of private well water, as compared to municipal drinking water, was associated with increased risk. (87)

Some smaller waterborne outbreaks of *Campylobacter*iosis have been associated with recreational exposure to water in lakes or swimming pools (107, 156, 287). One outbreak was caused by contaminated bagged ice (158).

<u>Other routes of infection</u>

Since *Campylobacter* may be excreted in animal feces at concentrations as high as 10^8 cfu/g, it is reasonable to expect that hides and feathers of farm animals may be contaminated. Several outbreaks were traced to lambs, calves, chickens, and pigs encountered by children during visits to farms and petting zoos (179, 244, 247). In addition, farm workers may contract *Campylobacter*iosis from livestock, including turkeys (72) and sheep (267). Abattoir workers also have occupational exposure to *Campylobacter* and may be colonized while handling chickens (73).

Person to person spread of *Campylobacter* spp. is not frequently observed but has been documented in intensive care wards in hospitals (115), in a day care center (96), and through sexual contact in homosexual men (91).

An unusual vehicle for *Campylobacter*iosis was reported to be ingestion of mud by 225 symptomatic racers during a mountain bike race in Canada in 2007 (250).

INTERVENTIONS

Epidemiological evidence indicates that a large proportion of human cases of campylobacteriosis result from contaminated poultry, particularly by cross-contamination in food preparation areas from raw chicken to other foods that will be consumed without further cooking. Consequently, there has been a great deal of thought and discussion on effective strategies for reducing exposure of live poultry flocks to *Campylobacter* and for minimizing contamination of poultry carcasses with pathogens, living in the ceca, during processing at abattoirs. It is likely impossible to ensure the absence of *Campylobacter* on all chicken, but this should be acceptable. Unlike other pathogens, such as *Listeria* and Salmonella, *Campylobacter* cannot increase in numbers on meat and so a small number of these bacteria on carcasses will not increase to dangerous levels during chilled storage or even moderate temperature abuse. However, food handlers and consumers should understand the potential for cross-contamination in the kitchen and how to prevent it.

EFSA (European Food Safety Authority) proposed and summarized evidence for several strategies for controlling *Campylobacter* along the poultry production and processing chain. (76) Strict implementation of biosecurity measures at farms may reduce colonization of chickens and other practices such as the use of fly screens and some changes in husbandry practices may further decrease the number of *Campylobacter* positive flocks. GMP/HACCP plans, including hot water and chemical carcass decontamination, may reduce bacterial numbers on carcasses

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during slaughter. Freezing carcasses for 2-3 weeks can reduce human health risk from contaminated meat by as much as 90%. A reduction of >50% in public health risk from *Campylobacter* could be achieved if all batches of poultry complied with a critical limit of 1000 cfu *Campylobacter*/gram of neck skin. Food Standards Agency of the UK has recently updated its strategy to better control campylobacteriosis (84). WHO also published a recent report discussing the worldwide problem of campylobacteriosis and poultry production systems in different countries necessitating different strategies for control of this pathogen (282).

New Zealand experienced an increasing rate of campylobacteriosis, starting in the 1980s and peaking in 2006. A range of voluntary and regulatory interventions targeting the poultry industry and consumer behavior were undertaken at about this time and resulted in a significant drop in incidence of campylobacteriosis. A study of the cost effectiveness of these interventions found that the health benefits exceeded the costs of preventive measures.(152, 236)

<u>Preharvest Control</u>

Biosecurity measures to prevent importation of *Campylobacter* or *Campylobacter*-positive animals into a farm are a first line of defense. In addition, good hygiene measures and husbandry practices can prevent or decrease colonization of animals. But these strategies are not completely effective and other measures have been investigated.

- Drinking water is suspected to be a means of spreading *Campylobacter* through chicken flocks (245). This cycle may be interrupted by thorough cleaning of the water distribution system in broiler houses. Addition of bactericidal agents such as electrolyzed oxidizing water (38) and organic acids (111) can also decrease contamination of water with *Campylobacter*.
- Administration of bacteriophages, that lyse *Campylobacter,* to chickens in an attempt to reduce pathogen loads has been reviewed recently. Many phage preparations have been shown to significantly reduce *Campylobacter* levels within a few days. However, the effectiveness of this technique depends on the susceptibility of the resident population (not all *Campylobacter* strains can be infected by a particular phage) (139). Furthermore, when susceptible *Campylobacter* die off, they may be replaced by more resistant *Campylobacter* strains and this may not reduce overall numbers of pathogens (83). It has been suggested that addition of bacteriophages to poultry drinking water a few days before slaughter might be effective in reducing contamination of birds during processing (140).
- Oral administration of antibodies, raised against flagellar proteins (213) or colonization associated proteins (8) of *Campylobacter*, to chicks reduced colonization of the ceca by *C. jejuni*.
- Several attempts to produce to produce commercially useful vaccines to prevent *Campylobacter* colonization of chickens have had little success. (14, 286)
- Probiotic cultures fed to chickens have reduced carriage of salmonellae and ongoing research is testing whether this strategy will reduce colonization by *Campylobacter.* Although some early studies suggested that this approach might work (235), other more recent in vivo trials have produced mixed results and significant inhibition of *Campylobacter* has not been observed in large trials under farm conditions (4, 218)

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- Effect of the addition of several organic compounds and phytochemicals to poultry feed on *Campylobacter* levels in chickens has been reviewed (268). One potential problem with using phenolic compounds as inhibitors of *Campylobacte*r is that some bacterial drug efflux systems can actively expel these compounds from *Campylobacter* cells (141).
- Flies are potential transport hosts for *Campylobacter* and some other zoonotic pathogens. Fly screens installed on commercial broiler houses in Denmark reduced the prevalence of *Campylobacter* positive flocks from 41.4% to 10.3% (22).
- Tests with pigs found that *Campylobacter* levels in cecae could be reduced by including lupine in feed for one week before slaughter (130) and in feces of piglets by adding high levels of zinc oxide (3.1 g ZnO/kg feed) to feed (35).
- Other feed additives have also been tested for controlling *Campylobacter* colonization of swine. Results have been mixed and some interventions decrease feed efficiency in the animals. (21)

Slaughterhouse hygiene

In a study in The Netherlands, scientists estimated that establishment of a critical limit of 1000 cfu *Campylobacter*/g raw chicken could reduce the number of human illnesses by about two thirds. Surveys of chicken processed at slaughterhouses showed that about one third of the batches exceeded this critical limit. Performance by individual slaughterhouses varied: In the poorest performing slaughterhouses, 57-65% of batches exceeded the limit while in the best slaughterhouses only 4-11% of batches exceeded the limit. Improving performance would likely entail some increased costs for processors but the estimated savings in economic costs caused by illness in the general population was estimated to be about four times greater. (252)

Strategies to determine food safety performance objectives for *Campylobacter* on broiler carcasses after chilling were discussed using quantitative methods to determine an objective for a maximum concentration of this bacterium that would accomplish an appropriate level of protection (established by regulatory authorities). The EU is considering establishing such microbiological criteria for *Campylobacter*. (58)

Chilling of carcasses is an important step in processing. Of three chilling methods tested (immersion chill, air chill, and a combination in line air chill), the immersion chill was most effective and reduced *Campylobacter* levels by 43%. This was likely due to the presence of chlorine as well as the washing effect. (61) Several methods for cleaning poultry carcasses have been described.

- A combination of steam and ultrasound was found to significantly reduce *Campylobacter* levels on poultry carcasses in Danish slaughterhouses (184)
- Use of electrolyzed oxidizing water and lactic acid in rinsing tanks resulted in small decreases of 1 to 1.5 log of *Campylobacter* on chicken carcasses (211)

Control strategies for meat and other foods

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Meats are usually cooked and milk is usually pasteurized before consumption and these thermal processes should kill any *Campylobacter* cells present. D values for *C. jejuni/coli* at 55, 60, 65, and 72ºC have been reported as 50, 8.2, 1.3, and 0.1 seconds, respectively (243). D values were determined for other species of *Campylobacter* using an immersed coil apparatus and nine models were assessed to determine thermal inactivation (231). However, D values are commonly determined when cells suspended in laboratory media and factors associated with real foods are known to be protective. Some experiments measuring D values for *Campylobacter* on chicken breasts during cooking by boiling demonstrated that the actual decimal reduction time during normal cooking can be as long as 1.9 minutes. A surface probe indicated that the temperature at the surface of the chicken reached 85ºC within a minute. In these trials, the chicken was inoculated with *Campylobacter* and then refrigerated overnight. This period of cold storage appeared to give the bacterial cells time to adhere to the surface of the meat and this attachment offered some protection from heat. (59) Therefore, depending on the level of *Campylobacter* contamination on chicken, some consumer practices for cooking large pieces of meat may be inadequate to kill all bacterial pathogens.

Several other processes have been tested for reducing *Campylobacter* loads on meat.

- Freezing of naturally contaminated chicken livers at -25ºC for 24 hours reduced *Campylobacter* levels by about 2 logs but did not completely eliminate the pathogen (108).
- *Campylobacter* on the surface of chicken meat and on food contact surfaces is killed by high intensity near-UV light but effectiveness is influenced by time of exposure and distance of the light from the surface. (110)
- Pulsed electric fields were found to reduce *Campylobacter* concentrations by about 4 to 7 logs in liquid media but had no significant effect on *Campylobacter* on the surface of pieces of chicken (112)
- Some marinades applied to poultry meat can reduce contamination level of *Campylobacter* (200, 258).
- Packaging of chicken legs under a modified atmosphere (30% CO_2, 70% N_2) with a culture of *Bifidobacterium longum* caused only a 1.16 log decline in *Campylobacter* levels (175)

Raw milk is another important vehicle for campylobacteriosis. Outbreaks associated with raw milk have been increasing in the U.S. (183) A recent review summarized data on disease outbreaks associated with raw milk in the USA and regulations in states where outbreaks occurred (153). Unfortunately, people who believe that raw milk is healthier to consume than pasteurized milk, often give raw milk to more vulnerable members of the population – young children and the elderly. A recent review summarized scientific evidence for the reported benefits of raw milk and for the presence of pathogens in unheated milk. With the exception of some alteration in the flavor of milk, pasteurization does not appear to affect the nutrients in milk while it does kill pathogenic bacteria. (51) This information should be more widely disseminated.

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Occupational exposure to *Campylobacter* can be reduced by better education of workers to reduce exposure and ensure better hygiene practices during and after handling animals. The National Association of State Public Health Veterinarians updated its recommendations for preventing disease associated with animals in public settings in 2013 (270). County fairs and petting zoos have been sites for a number of enteric disease outbreaks and procedures to protect children and the general public from becoming infected with *Salmonella* and *E. coli* should also protect them from *Campylobacter*.

Completely preventing *Campylobacter* contamination of meat and other foods is impossible. So food handlers and consumers should be educated about safe preparation of foods. Research has shown that many persons preparing food at home are either unaware of or do not practice safe handling practices to prevent cross-contamination. (26, 117, 177)

SUMMARY

Campylobacteriosis is a widespread food- and water-borne gastrointestinal illness, caused primarily by *C. jejuni* and *C. coli*. In most cases morbidity is moderate but in some cases, long term sequelae, including Guillain-Barre syndrome, reactive arthritis and irritable bowel may persist for months or years. According to some estimates, about 30% of cases result from consumption and preparation of poultry meat. Unpasteurized milk and drinking water contaminated be sewage or run-off from fields have also been implicated in many outbreaks.

Although some smaller countries have successfully reduced their prevalence of campylobacteriosis, many other countries have seen increasing or stable levels of this disease in spite of attempts to reduce contamination levels in poultry. Many surveys of retail poultry meat still find that a large proportion carry *Campylobacter*. (274) This review summarizes much of the latest information on campylobacteriosis and interventions which are being used or investigated to reduce contamination of food and water.

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Figure 1.

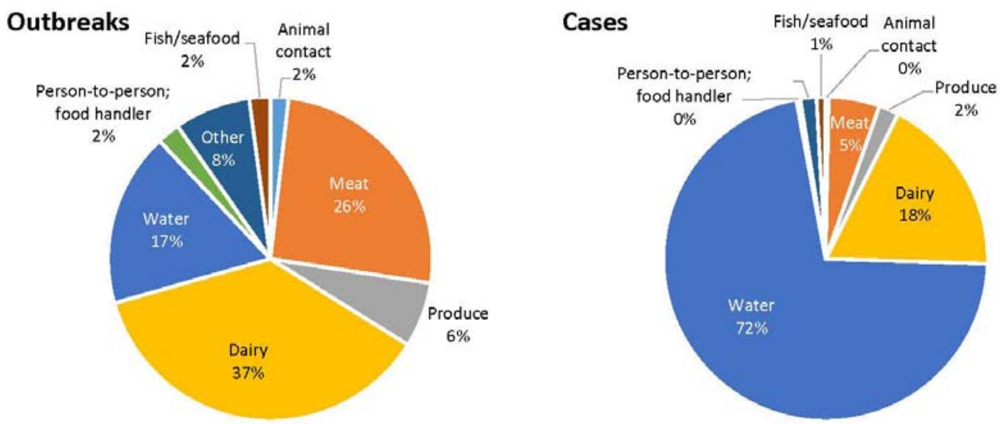

Figure 2. Vehicles (except for drinking water) associated with published reports of outbreaks and cases of *Campylobacter* infections.

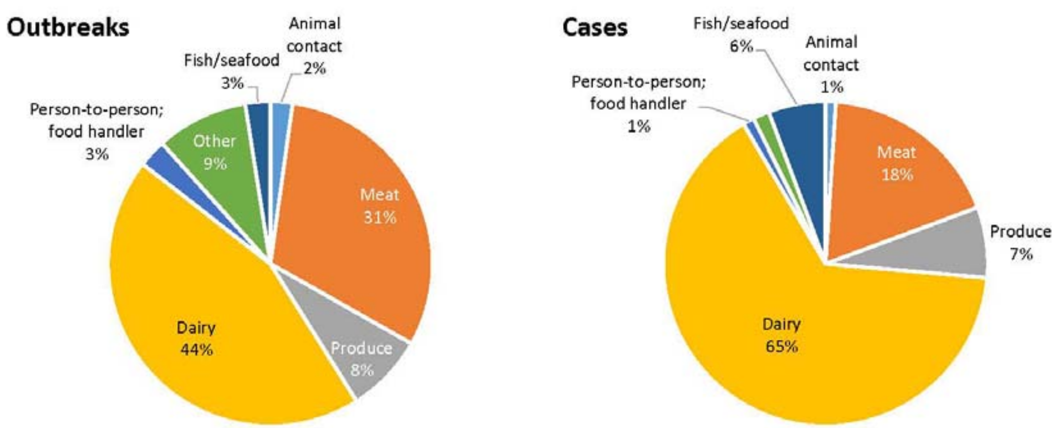

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Figure 3. Different meat vehicles associated with published reports of outbreaks and cases of *Campylobacter* infections.

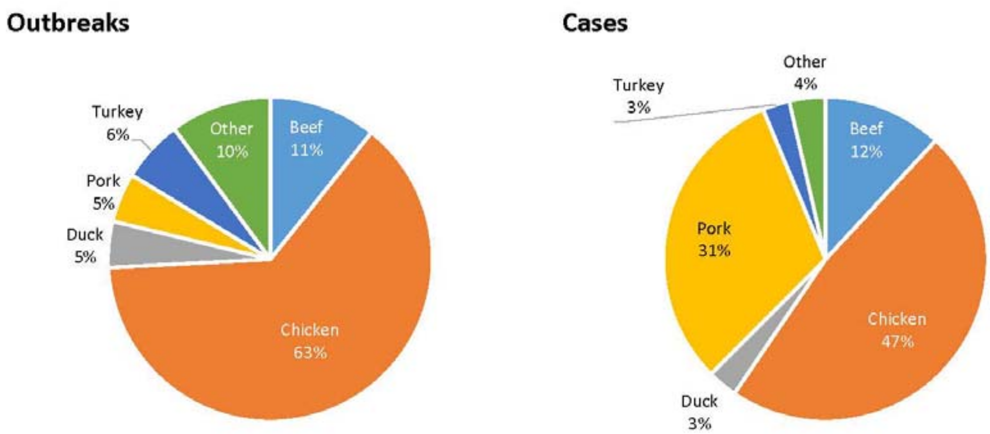

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Table 1. Large foodborne outbreaks (>85 cases) of *Campylobacter*

Year	# Cases	Species	Location; Vehicle	Reference
1979	3500	*C. jejuni*	UK; raw milk	(133, 216)
2006	1644	*C. jejuni*	US; pasteurized milk	(47)
1980	800	*C.* spp.	Japan: vinagered pork	(284)
1982	400	*C.* spp.	UK; raw milk	(15)
1938	357	*V. jejuni*	US; raw milk	(157)
1998	300	*C. jejuni*	US; lettuce	(47)
2008	268	*C. jejuni*	US; clams	(47)
2007	225	*C. jejuni*	Canada; mud	(250)
1981	208	*C.* spp.	US; raw milk	(254)
1979	205	*C.* spp.	Scotland; raw milk	(205)
2005	200	*C. jejuni*	US; pasteurized milk	(47)
2012	148	*C. jejuni*	US; raw milk	(165)
1981	145	*C.* spp.	UK; raw milk	(15)
1982	145	*C.* spp.	UK; raw milk	(15)
2002	136	*C. jejuni*	US; salads	(47)
2008	132	*C. jejuni*	US; peas	(90)
1998	128	*C. jejuni*	US; potato, pineapple, gravy	(47)
1992	110	*C. jejuni*	UK; raw milk	(78)
1978	100	*C.* spp.	UK; raw milk	(216)
2009	92	*C. jejuni*	Korea; chicken	(288)
1979-81	91	*C. jejuni*	US; raw milk	(256)
2005	86	*C. jejuni*	Scotland; chicken liver paté	(85)
1980	86	*C.* spp.	UK; raw milk	(257)

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Table 2. Large waterborne outbreaks (>400 cases) of *Campylobacter* reported in 1978 to 2013

Year	Cases	Species	Country	Contamination by	Reference
2007	6500	*C. jejuni*, others	Finland	Cross connection between sewage and drinking water pipes	(150)
1978	3000	*C. jejuni*	US: VT	Agricultural runoff following heavy rain; inadequate chlorination	(272)
1995	3000	*C.* spp.	Sweden	Unknown contamination of tap water	(12)
1998	2700	*C.* spp.	Finland	Water main repairs	(147)
2000	2600	*C. coli*, rotavirus, norovirus	France	Agricultural runoff; chlorination failure	(89)
1994	2500	*C.* spp.	Sweden	Contaminated surface water source	(12)
2000	2300	*C. jejuni*, *E. coli* O157:H7	Canada (Walkerton)	Agricultural runoff	(52)
1979	2000	*C. jejuni*	Sweden	River water contaminated drinking water because mains did not have non-return valves; no chlorination	(176)
1998	1607	*C. jejuni*, *Shigella*, norovirus	Switzerland	Pump failure spilling sewage into ground water	(173)
2004	1450	*C. jejuni*, norovirus, *Giardia*, *Salmonella*	US: OH	Irregularities in sewage disposal contaminating ground water	(196)
1980	1300	*C. jejuni*	US: CT	Inadequately treated reservoir water	(32)
2000	900	*C. jejuni*	Finland	Non-chlorinated groundwater supply	(146)

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1983	865	*C. jejuni*	US: FL	Failure of chlorination; open top treatment towers with birds perching on top	(222)
1999	781	*C. jejuni*, *E. coli*	US: NY	Shallow well at county fair	(194)
1988	680	*C. jejuni*	Norway	Agricultural runoff; unchlorinated water	(174)
1995	633	*C.* spp., *E. coli*	UK	Contaminated stream water	(132)
2010	628	*C. jejuni*	US: UT	Cross-connection between potable and non-potable water sources	(116)
2010	409	*C. jejuni*	Denmark	Contamination of tap water	(100)

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Appendix: Campylobacter Outbreaks*

Year	Species	Location	Cases	Hosp.	Vehicle	Reference
1938	*Vibrio jejuni*	US: IL	357	151	Milk, raw	(*107*)
1978	*C. jejuni*	US: CO	3		Milk, raw	(*15*)
1978	*C. jejuni*	US: VT	3000		Water	(*169*)
1978	*C. jejuni*	US: CO	7		Animal contact: sick dog	(*17*)
1978	*C.* spp.	UK	100		Milk, raw	(*141*)
1978	*C.* spp.	UK	64		Milk, raw	(*141*)
1978	*C.* spp.	UK	16		Milk, raw	(*141*)
1978	*C. jejuni*	Netherlands	89	24	Chicken, undercooked	(*27*)
1979	*C. jejuni*	US: IA	3		Chicken, undercooked	(*147*)
1979	*C. jejuni*	US: IA	2		Chicken, undercooked	(*147*)
1979	*C. jejuni*	US: NM	41		Milk, raw	(*18*)
1979	*C. jejuni*	US: CO	8		Person-to-person	(*18*)
1979	*C. jejuni*	US: MI	4		Person-to-person	(*19*)
1979	*C. jejuni*	US: MI	4		Person-to-person	(*19*)
1979	*C. jejuni*	Scotland	205		Milk, raw	(*135*)
1979	*C. jejuni*	UK	3500		Milk, raw	(*95; 141*)
1979	*C. jejuni*	UK	75		Milk, raw	(*141*)
1979	*C.* spp.	UK	13		Milk, raw	(*141*)
1979	*C.* spp.	UK	4		Milk, raw	(*141*)
1979	*C. jejuni*	UK	14		Milk, raw	(*141*)
1979	*C. jejuni*	Japan	37		Food, unknown (school)	(*89*)
1980	*C. jejuni*	Sweden	2000	7	Water, drinking, unchlorinated	(*117*)
1980	*C. jejuni*	Sweden	37		Animal contact: poultry (abattoir)	(*32*)
1980	*C. jejuni*	Canada	27		Milk, raw	(*29; 114*)
1980	*C.* spp.	Japan	800		Pork, vinagered	(*174*)
1980	*C.* spp.	UK	86		Milk, raw	(*164*)
1980	*C. jejuni*	UK	75		Milk, raw	(*141*)
1980	*C. jejuni*	UK	40		Milk, raw	(*141*)
1980	*C.* spp.	UK	8		Milk, raw	(*141*)
1980	*C. jejuni*	UK	21		Chicken, undercooked	(*150*)
1980	*C. jejuni*	US: CT	1300		Water	(*141*)
1980	*C. jejuni*	US: WY	21		Water	(*18*)
1980	*C. jejuni*	US: CT	41		Cake icing; salad	(*16; 18*)
1980	*C. jejuni*	US: MN	9		Chicken	(*43*)
1980	*C. jejuni*	US: CA	11		Turkey, processed	(*18*)
1979–1981	*C. jejuni*	US: CA	10		Liver, raw, calves	(*51*)
1980–1981	*C. jejuni*	US: OR	91		Milk, raw	(*163*)
1981	*C. jejuni*	UK	46		Milk, raw	(*173*)
1981	*C. jejuni*	UK	22		Milk, raw	(*173*)
1981	*C. jejuni*	Sweden	66		Chicken	(*23*)
1981	*C. jejuni*	Netherlands	9		Person-to-person	(*166*)
1981	*C. jejuni*	US: AZ	208	2	Milk, raw	(*162*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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1981	*C. jejuni*	US: MN	25		Milk, raw	(*99*)
1981	*C. jejuni*	US: CO	2		Milk, raw	(*18*)
1981	*C. jejuni*	US: KS	60	1	Milk, raw	(*100*)
1981	*C. jejuni*	US: GA	50		Milk, raw	(*136*)
1981	*C. jejuni*	US: IL	78		Water, drinking	(*161*)
1981	*C. jejuni*	US: IL	7	2	Salad	(*52*)
1981	*C. jejuni*	US: NY	3		Food, restaurant	(*43*)
1981	*C. jejuni*	US: NY	19		Beef, egg	(*43*)
1981	*C. jejuni*	US: ME	3		Milk, raw	(*43*)
1981	*C. jejuni*	US: AZ	14		Milk, raw	(*43*)
1981	*C. jejuni*	US: ME	14		Milk, raw	(*43*)
1981	*C. jejuni*	US: NY	10		Food, fraternity	(*43*)
1981	*C. jejuni*	US: GA	18		Milk, raw	(*136*)
1981	*C. jejuni*	UK	258		Water, drinking, unchlorinated	(*131*)
1982	*C.* spp.	UK	145		Milk, raw	(*8*)
1982	*C.* spp.	UK	42		Milk, raw	(*8*)
1982	*C.* spp.	UK	~400		Milk, raw	(*8*)
1982	*C. jejuni*	US: MD	46		Milk, raw	(*43*)
1982	*C. jejuni*	US: GA	6		Chicken	(*43*)
1982	*C. jejuni*	US: MI	32		Milk, raw	(*43*)
1982	*C. jejuni*	US: ME	32		Milk, raw	(*43*)
1982	*C. jejuni*	US: MN	26		Eggs	(*43*)
1982	*C. jejuni*	US: VT	15		Milk, raw	(*43*)
1982	*C. jejuni*	US: VT	4		Milk, raw	(*43*)
1982	*C. jejuni*	US: WA	2		Food, Chinese	(*43*)
1982	*C. jejuni*	Israel	22		Food handler	(*34*)
1982	*C. jejuni*	Israel	150		Water, drinking	(*143*)
1982	*C.* spp.	New Zealand	51		Milk, raw	(*24*)
1982	*C. jejuni*	US: WI	15		Milk, raw	(*98*)
1982	*C. jejuni*	US: CO	11	0	Chicken, undercooked	(*88*)
1983	*C. jejuni*	UK	75		Milk, raw	(*85*)
1983	*C. jejuni*	US: FL	865	4	Water, drinking	(*146*)
1983	*C. jejuni*	US: PA	31	0	Milk, raw	(*20*)
1983	*C. jejuni*	US: WA	6		Milk, goat, raw	(*76*)
1983	*C. jejuni*	US: PA	26	1	Milk, raw	(*20*)
1983	*C. jejuni*	US: VT	13		Milk, raw	(*83*)
1983	*C.* spp.	New Zealand	38		Milk, raw	*(24)*
1983	*C. jejuni*	Australia	7		Chicken	(*145*)
1984	*C. jejuni*	US: CA	12		Milk, raw	(*137*)
1984	*C. jejuni*	Norway	300		Water, drinking	(*35*)
1984	*C. coli*	UK	3	0	Milk, goat, raw	(*86*)
1984	*C. jejuni*	France	11	11	Nosocomial	(*54*)
1984–1986	*C. jejuni*	UK	19		Chicken	(*133*)
1985	*C. laridis*	Canada	162		Water, drinking	(*26*)
1985	*C. jejuni*	Canada	241		Water, drinking	(*119*)
1985	*C. jejuni*	US: AR	19		Water, drinking	(*156*)
1985	*C. jejuni*	US: WI	150		Water, drinking	(*156*)
1985	*C. jejuni*	US: CA	25		Milk, raw	(*11*)
1985	*C. jejuni*	US: WI	16	2	Cantaloupe	(*21*)
1986	*C. jejuni*	Israel	7		Person-to-person	(*78*)
1986	*C.* spp.	New Zealand	19		Water, drinking	(*25*)
1986	*C.* spp.	Canada	50		Water, drinking	(*82*)
1986	*C. jejuni*	US: VT	35		Milk, raw	(*12*)
1987	*C. jejuni*	Finland	79		Water, drinking	(3)
1987	*C. fetus*	Japan	7		Nosocomial	(*124*)
1987	*C. jejuni*	Canada	18		Water, drinking	(*4*)
1988	*C. jejuni; C. coli*	Norway	330		Water, drinking	(*116*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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1988	*C. jejuni*	Norway	680		Water, drinking	(*115*)
1990	*C. jejuni*	New Zealand	44		Water, drinking	(*157*)
1990	*C.* spp.	US: WA	13		Milk, raw	*(189)*
1990	*C. jejuni*	US: TX	42		Milk, raw	*(189)*
1991	*C. jejuni*	UK	11		Milk, contaminated by birds	(*140*)
1991	*C. jejuni*	US: NY	20		Meats, cold tray	*(188)*
1991	*C. jejuni*	US: PA	10		Chicken, fruit	*(188)*
1991	*C. jejuni*	US: WA	3		Milk, goat, raw	*(188)*
1991–1992	*C. upsaliensis*	Belgium	44		Person-to-person	(*53*)
1992	*C.* spp.	UK	72		Milk, raw	(*123*)
1992	*C. jejuni*	UK	110		Milk, raw	(*41*)
1992	*C.* spp.	US: ME	11		Milk, raw	*(187)*
1992	*C. jejuni*	US: IN	34		Pasta salad, potatoes	*(187)*
1992	*C. jejuni*	US: MN	50		Milk, raw	*(187)*
1992	*C. jejuni*	US: NY	23		Milk	*(187)*
1993	*C.* spp.	UK	8	0	Water, drinking	(*45*)
1993	*C.* spp.; *Cryptosporidium*	UK	43	2	Water, drinking (lamb carcasses)	(*36*)
1993	*C. coli*	UK	36	0	Water, drinking	(*45*)
1993	*C. jejuni*	US: NY	172		Water, drinking	(*101*)
1993	*C. jejuni*	US: MN	32		Water, drinking	(*101*)
1993	*C. jejuni*	US: MN	48		Melon, strawberries	*(186)*
1994	*C. jejuni*	Canada	7		Animal exposure: turkeys	(*38*)
1994	*C. jejuni*	US: MN	19		Water, drinking	(*101*)
1994	*C. jejuni*	US: MN	62		Fruit salad	*(185)*
1994	*C. jejuni*	UK	23		Milk, raw	(*40*)
1994	*C. jejuni*	UK	53	0	Water, drinking	(*45*)
1994	*C.* spp.	UK	8	0	Water, drinking	(*45*)
1994	*C. jejuni*	UK	22	0	Water, drinking	(*45*)
1994	*C.* spp.	UK	12		Chicken, undercooked	(*125*)
1994	*C.* spp.	UK	41		Water, drinking	(*151*)
1994	*C.* spp.	Sweden	2500		Water, drinking	(*7*)
1995	*C.* spp.	Sweden	3000		Water, drinking	(*7*)
1995	*C. coli*	Belgium	24		Salad, mixed, with ham & cheese	(*144*)
1995	*C.* spp.; *E. coli*	UK	633		Water, drinking	(*94*)
1995	*C.* spp.	UK	12		Milk, bird-pecked bottles	(*159*)
1995	*C.* spp.	US: OH	7		Water: bagged ice	(*108*)
1995	*C. jejuni*	US: WI	79		Tuna salad	(*142*)
1995	*C.* spp.	US: WI	11		Beef barbecue	*(184)*
1995	*C. jejuni*	US: FL	17		Chicken, cole slaw	*(184)*
1995	*C. jejuni*	US: NY	9		Pork	*(184)*
1996	*C. jejuni*	US: OK	14	2	Lettuce, contaminated by raw chicken	(*56*)
1996	*C. jejuni*	US: NY	29		Milk	*(183)*
1996	*C. jejuni*	US: NY	70		Salad	*(183)*
1997	*C.* spp.	Australia	23		Water, drinking	(*118*)
1997	*C. jejuni*	Northern Ireland	12		Salad, lettuce & tomato	(*122*)
1997	*C.* spp.	US: CT	17	3	Sweet potatoes, other foods (1 death)	(*172*) *(182)*
1997	*C.* spp.	US: FL	4		Shellfish	*(182)*
1997	*C. jejuni*	UK	12		Chicken, undercooked	(*39*)
1997	*C. jejuni*	UK	52		Chicken and other foods	(*50*)
1998	*C. jejuni*	Austria	38		Milk, raw	(*106*)
1998	*C. jejuni*	Finland	~2700	7	Water, drinking, unchlorinated	(*103*)
1998	*C. jejuni*; *C. coli*	Hungary	34		Milk, raw	(*96*)
1998	*C. jejuni*; *Shigella*; norovirus	Switzerland	1607		Water, drinking	(*112*)
1998	*C.* spp.	US: FL	16	1	Chicken	(*31*)
1998	*C. jejuni*	US: KS	129	2	Gravy, pineapple; food handler	(*129*)

1998	*C. jejuni*	US: MN	300	0	Lettuce	(*31*)
1998	*C. jejuni*	US: SD	6	1	Milk, raw	(*31*)
1998	*C.* spp.	US: NY	3		Milk, raw	(*31*)
1998	*C. jejuni*	US: WA	2	0	Oysters	(*31*)
1998	*C. jejuni*	US: FL	3		Fish, salmon and tuna, raw	(*31*)
1998	*C.* spp.	US: FL	3	1	Chicken sandwich	(*31*)
1998	*C. jejuni*	US: WI	16	0	Salad, taco or nacho	(*31*)
1998	*C. jejuni*; *S. enterica*	US: OR	22	1	Turkey	(*31*)
1999	*C. jejuni*	US: CA	13	1	Chicken	(*31*)
1999	*C.* spp.	US: FL	2	0	Food, ethnic	(*31*)
1999	*C. jejuni*	US: WA	2		Milk, raw	(*31*)
1999	*C. jejuni*	US: MD	34	0	Beef	(*31*)
1999	*C.* jejuni; E. *coli*	US: NY	781	71	Water, drinking	(*105; 126)*
1999	*C. jejuni*	US: FL	6		Water, swimming pool	(*105*)
2000	*C. jejuni*	US: ID	15		Water, drinking	(*105*)
2000	*C. jejuni*	US: UT	102		Water, irrigation, used for drinking	(*105*)
2000	*C. coli*; rotavirus; norovirus	France	2600		Water, drinking	(*46*)
2000	*C. jejuni*	UK	281		Water, drinking	(*139*)
2000	*C. jejuni*	Finland	~900		Water, drinking, unchlorinated (Nokia)	(*102*)
2000	*C. jejuni*; *E. coli* O157:H7	Canada (Walkerton)	2300		Water, drinking	(*33*)
2000	*C.* spp.	UK	14	4	Water, drinking	(*9*)
2000	*C. jejuni*	US: multistate	18	0	Cheese, raw milk	(*31*)
2000	*C. jejuni*	US: CT	13	1	Lettuce-based salads	(*31*)
2000	*C. jejuni*	US: PA	3	1	Milk, pasteurized	(*31*)
2000	*C. jejuni*	US: WI	19	0	Milk, raw	(*31*)
2000	*C.* spp.	US: TX	2		Milk, raw	(*31*)
2000	*C. jejuni*	US: OK	11	1	Milk, raw	(*31*)
2000	*C. jejuni*	US: OK	21	2	Milk, raw	(*31*)
2000	*C.* spp.	US: MN	8	1	Milk, raw	(*31*)
2000	*C. jejuni*	US: ID	42	1	Milk, raw	(*31*)
2000	*C. jejuni*	US: NY	39		Milk, whole, raw	(*31*)
2000	*C. jejuni*	US: ID	4	0	Milk, whole, raw	(*31*)
2000	*C. jejuni*	US: WY	8		Animal contact: pheasants	(*79*)
1999–2001	*C. jejuni*	Canada	11		Person-to-person	(*49*)
2000–2001	*C. jejuni*; *E. coli*; *Cryptosporidium*; *Salmonella*	US: MN	84		Animal contact: calves	(*155*)
2001	*C. jejuni*	Australia	3		Chicken	(*58*)
2001	*C.* spp.	Australia	2		Duck liver	(*60*)
2001	*C.* spp.	Australia	6		Milk, raw	(*60*)
2001	*C.* spp.	Australia	48		Salad	(*59*)
2001	*C.* spp.	Australia	49		Food, unknown	(*59*)
2001	*C. jejuni*	Australia	10		Food, restaurant	(*138*)
2001	*C. jejuni*	Germany	5		Chicken	(*5*)
2001	*C. jejuni*; *S. enterica*	US: WI	80		Beef, steak	(*31*)
2001	*C. jejuni*	US: CA	3	0	Chicken	(*31*)
2001	*C. jejuni*	US: WY	4	0	Chicken; dumplings	(*31*)
2001	*C.* spp.	US: OH	3	0	Chicken, other; lettuce-based salads	(*31*)
2001	*C. jejuni*	US: MD	14		Chicken	(*31*)
2001	*C. jejuni*	US: AZ	62	4	Chicken and beef enchilada	(*31*)
2001	*C.* spp.	US: FL	2	1	Food, ethnic buffet	(*31*)
2001	*C. jejuni*	US: MD	14		Fruit salad	(*31*)
2001	*C. jejuni*; *S. aureus*	US: WI	20	3	Meat	(*31*)
2001	*C. jejuni*	US: NY	16		Potato salad	(*31*)
2001	*C. jejuni*	US: NE	24	1	Potato salad	(*31*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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2001	*C. jejuni*	US: WA	2	0	Quail	(*31*)
2001	*C.* spp.	US: NY	3		Beef sandwich; chicken Parmesan sandwich	(*31*)
2001	*C. jejuni*	US: WI	75	0	Milk, whole, raw	(*75*)
2001	*C. jejuni*	US: MN	4	0	Milk, whole, raw	(*31*)
2001	*C. jejuni*; *Y. enterocolitica*	US: AK	12		Water, drinking	(*14*)
2001	*C. jejuni*	US: WI	13		Water, drinking	(*14*)
2002	*C. jejuni*; *Entamoeba*; *Giardia*	US: NY	27		Water, drinking	(*109*)
2002	*C. jejuni*	Australia	24		Chicken	(*61*)
2002	*C. jejuni*	Finland	6	1	Milk, raw	(*148*)
2002	*C.* spp.	US: MN	3	1	Animal contact: chickens, pigs	(*158*)
2002	*C.* spp.	US: MN	9	0	Animal contact: turkeys	(*158*)
2002	*C. jejuni*	US: CA	3	0	Pork burrito	(*31*)
2002	*C. jejuni*	US: CA	3	1	Burrito; salsa	(*31*)
2002	*C. jejuni*	US: FL	8		Chicken, BBQ	(*31*)
2002	*C. jejuni*	US: FL	4	1	Chicken, buffalo wings	(*31*)
2002	*C.* spp.	US: MO	18	0	Chicken; mashed potato/gravy; vegetables	(*31*)
2002	*C. coli*	US: AR	7	0	Salad, green	(*31*)
2002	*C. jejuni*	US: WA	136	1	Salads, green, pasta, tuna	(*31*)
2002	*C. jejuni*	US: CA	50	5	Guacamole	(*31*)
2002	*C.* spp.	US: CA	5	0	Liver	(*31*)
2002	*C. jejuni*	US: KS	46	1	Milk, raw	(*31*)
2002	*C.* spp.	US: CA	12	0	Milk, raw	(*31*)
2002	*C. jejuni*	US: WA	2	0	Pizza, meat and vegetable	(*31*)
2002	*C. jejuni*	US: VA	20		Potato salad	(*31*)
2002	*C.* spp.; *S. enterica*	US: CA	6	0	Salsa	(*31*)
2002	*C.* spp.	US: WA	2	0	Beef sandwich	(*31*)
2002	*C.* spp.	US: MN	4	0	Salads	(*31*)
2002	*C. jejuni*	US: WA	2	0	Milk, whole, raw	(*31*)
2002	*C. jejuni*	US: UT	13	0	Milk, whole, raw	(*134*)
2003	*C.* spp.	Australia	2	1	Caesar salad	(*62*)
2003	*C.* spp.	Australia	19	0	Chicken	(*62*)
2003	*C.* spp.	Australia	13	0	Milk, raw	(*62*)
2003	*C. jejuni*; *S. enterica*	US: MN	15	2	Beef, raw	(*31*)
2003	*C. jejuni*	US: CA	4	0	Ceviche	(*31*)
2003	*C. jejuni*	US: WI	5	0	Chicken, baked	(*31*)
2003	*C.* spp.	US: WA	3	0	Chicken, fried	(*31*)
2003	*C. jejuni*	US: WA	2	0	Chicken, other	(*31*)
2003	*C. jejuni*	US: CA	5	0	Chicken	(*31*)
2003	*C.* spp.	US: CA	5	0	Chicken	(*31*)
2003	*C. fetus*	US: WA	9	1	Cheese, raw	(*31*)
2003	*C. jejuni*	US: OK	7	0	Ice cream, homemade	(*31*)
2003	*C. jejuni*	US: WI	3	0	Nachos	(*31*)
2003	*C. jejuni*	US: VT	18	0	Cheese, raw milk	(*31*)
2003	*C. jejuni*	US: WI	2	0	Milk, raw	(*31*)
2003	*C. jejuni*	US: MI	6	0	Milk, raw	(*31*)
2003	*C. jejuni*; *E. coli*	US: WA	3	0	Milk, raw	(*31*)
2003	*C.* spp.	US: CA	11	0	Cheese: queso fresco, raw	(*31*)
2003	*C.* spp.	US: OH	2	0	Soup; poultry/egg	(*31*)
2003	*C.* spp.	US: multistate	87		Water, tap	(*31*)
2003	*C.* spp.	US: WI	17	0	Turkey, roasted	(*31*)
2003	*C. jejuni*; *Cryptosporidium*	France	200		Water, drinking	(*10*)
2003	*C. jejuni*	Spain	81		Custard (contaminated by chicken)	(*93*)
2003	*C. jejuni*; *Shigella*	US: OH	57		Water, drinking	(*109*)
2003	*C.* spp.	US: WA	110		Water, drinking	(*109*)
2004	*C. jejuni*	US: OH	82		Water, drinking	(*109*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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2004	*C.* spp.	US: OH	1450		Water, drinking	(*109*)
2004	*C. jejuni*	US: VA	34		Water, drinking	(*109*)
2004	*C.* spp.	UK	36		Water, drinking	(*77*)
2004	*C. jejuni*; norovirus; *Giardia*; *Salmonella*	US: OH	1450	21	Water, drinking, sewage contamination	(*128*)
2004	*C.* spp.	Australia	21	1	Chicken	(*63*)
2004	*C.* spp.	Australia	2	0	Chicken	(*63*)
2004	*C.* spp.	Australia	4	1	Food, unknown	(*63*)
2004	*C.* spp.	Australia	24	2	Meat, barbecue	(*63*)
2004	*C.* spp.	Australia	7	0	Water	(*63*)
2004	*C. jejuni*	Australia	3		Sausage, pre-cooked	(*55*)
2004	*C. jejuni*	US: CO	2	0	Chicken, grilled	(*31*)
2004	*C. jejuni*	US: TX	9	0	Salad, green	(*31*)
2004	*C.* spp.	US: OH	5	1	Ice cream, homemade	(*31*)
2004	*C. jejuni*	US: CA	5	0	Liver	(*31*)
2004	*C. jejuni*; norovirus	US: MN	29	0	Cake/cookie dough, raw	(*31*)
2004	*C. jejuni*	US: FL	2		Salad bar	(*31*)
2004	*C.* spp.	US: OH	13	0	Tomato	(*31*)
2004	*C. jejuni*	US: CA	2		Turkey	(*31*)
2004	*C. jejuni*	US: IA	32	0	Milk, whole, raw	(*31*)
2004	*C.* spp.	US: WY	6	1	Milk, whole, raw	(*31*)
2005	*C. jejuni*	Japan	36		Chicken	(*175*)
2005	*C. jejuni*	Scotland	86		Chicken liver pâté	(*44*)
2005	*C. jejuni*	Denmark	79	1	Chicken	(*113*)
2005	*C.* spp.	Australia	11	1	Chicken	(*64*)
2005	*C.* spp.	Australia	4	0	Chicken	(*64*)
2005	*C. jejuni*	Australia	35		Foods, multiple	(*120*)
2005	*C.* spp.	Australia	11	1	Chicken	(*13*)
2005	*C. jejuni*	US: CO	200	1	Milk, 1%, pasteurized	(*31*)
2005	*C. jejuni*	US: CO	14	0	Beans, baked; potato salad	(*31*)
2005	*C. jejuni*	US: MD	4	0	Salad, caesar	(*31*)
2005	*C. jejuni*	US: OK	28	1	Beef and chicken fajita; onions; peppers	(*31*)
2005	*C. jejuni*	US: OK	11	3	Milk, goat and cow, raw	(*31*)
2005	*C. jejuni*	US: WI	13	2	Chicken liver	(*31*)
2005	*C.* spp.	US: WA	9	0	Chicken liver	(*31*)
2005	*B. cereus*; *C. jejuni*	US: CO	8	0	Noodles; quail	(*31*)
2005	*C. jejuni*	US: WY	3	0	Milk, raw	(*31*)
2005	*C. jejuni*	US: AK	18		Peas, green	(*47*)
2005	*C. jejuni*	US: WA	2	0	Sandwich, gyro	(*31*)
2005	*C.* spp.	US: CO	2	0	Dip, vegetable	(*31*)
2005	*C. jejuni*	US: KS	4	0	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: IA	33	0	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: WY	11	2	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: AZ	13	1	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: CO	5	0	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: UT	11	0	Milk, whole, raw	(*31*)
2005	*C. jejuni*	US: CO	22	0	Milk, whole, raw	(*31*)
2005	*C. jejuni*; *E. coli*	US: OR	60		Water, drinking	(*177*)
2005	*C. jejuni*	US: WY	6		Water, kiddie pool	(*176*)
2006	*C.* spp.	US: IN	32		Water, drinking	(*177*)
2006	*C. jejuni*	Australia	3	3	Chicken, undercooked	(*65*)
2006	*C. jejuni*	Australia	46	0	Water, drinking	(*65*)
2006	*C.* spp.	Australia	5	0	Chicken	(*65*)
2006	*C.* spp.	Australia	13	1	Unknown food	(*65*)
2006	*C. jejuni*	Japan	71		Water, tap, unchlorinated	(*1*)
2006	*C.* spp.	UK	48	2	Chicken liver pâté	(*127*)
2006	*C. jejuni*	Italy	5	5	Milk, raw	(*6*)
2006	*C. jejuni*	US: WY	141		Water, drinking, unchlorinated	(*167*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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2006	*C. jejuni*	US: WI	23	0	Beef; ham	(*31*)
2006	*C.* spp.	US: OH	13	2	Chicken, grilled; sausage, bratwurst	(*31*)
2006	*C.* spp.	US: CA	10	2	Chicken, pork, soy sauce	(*31*)
2006	*C. jejuni*	US: WA	10		Food, ethnic style	(*31*)
2006	*C. jejuni*	US: WI	58	2	Cheese, raw milk	(*31*)
2006	*C. jejuni*	US: CA	1644	7	Milk, pasteurized	(*92*)
2006	*C. jejuni*	US: CO	3	0	Oysters, raw	(*31*)
2006	*C. jejuni*	US: VA	9	0	Milk, raw	(*31*)
2006	*C. jejuni*; *S. enterica*	US: WI	2	2	Turkey, baked	(*31*)
2006	*C. jejuni*	US: VA	15	1	Watermelon	(*31*)
2006	*C. jejuni*	US: IL	18	0	Milk, whole, raw	(*31*)
2006	*C.* spp.	US: OH	3	1	Milk, whole, raw	(*31*)
2006	*C.* spp.	US: NY	2	0	Milk, whole, raw	(*31*)
2006	*C.* spp.	US: CO	5	4	Milk, whole, raw	(*31*)
2007	*C.* spp.	Australia	2	1	Meat	(*66*)
2007	*C.* spp.	Scotland	52		Chicken liver pâté	(*153*)
2007	*C. jejuni*	Canada	225		Mud, ingestion of	(*160*)
2007	*C.* spp.; other enteric pathogens	Finland	8453		Water, drinking; sewage contamination	(*104*)
2007	*C.* spp.	Norway	105		Water, drinking (est. total cases 1500)	(*91*)
2007	*C. jejuni*; *S. enterica*	US: WI	8	3	Beef	(*31*)
2007	*C. jejuni*	US: UT	62	4	Butter; goat milk and cheese, raw; milk, whole, raw	(*31*)
2007	*C.* spp.	US: CA	3	0	Candy, tamarindo	(*31*)
2007	*C. jejuni*	US: KS	16	0	Cheese, cheddar, raw; milk, raw	(*31*)
2007	*C. jejuni*	US: WA	3	1	Chicken	(*31*)
2007	*C. jejuni*	US: MI	11	0	Chicken	(*31*)
2007	*C. jejuni*	US: CO	26	4	Chili; ground beef, cheeseburger	(*31*)
2007	*C.* spp.	US: PA	3	0	Milk, ice cream, homemade	(*31*)
2007	*C. jejuni*	US: NY	2	0	Duck liver	(*31*)
2007	*C. jejuni*	US: KS	68	2	Cheese, soft, raw milk	(*31; 84)*
2007	*C. jejuni*	US: CO	4	1	Cheese	(*31*)
2007	*C. jejuni*	US: NH	13	2	Potato salad	(*31*)
2007	*C. jejuni*; *S. enterica*	US: SC	11	4	Milk, raw	(*31*)
2007	*C. jejuni*	US: GA	8	0	Milk, raw	(*31*)
2007	*C. jejuni*	US: WA	18	0	Milk, raw	(*31*)
2007	*C.* spp.	US: NY	2	1	Milk, raw	(*31*)
2007	*C. jejuni*	US: PA	4	0	Milk, raw	(*31*)
2007	*C. jejuni*	US: CA	11	0	Milk, raw	(*31*)
2007	*C.* spp.	US: NM	48	1	Ham sandwich	(*31*)
2007	*C. jejuni*	US: KS	13	0	Turkey, smoked	(*31*)
2007	*C.* spp.; *Salmonella*; norovirus	US: WI	229		Water, drinking	(*28*)
2007	*C.* spp.	US: WV	4		Water, drinking	(*28*)
2008	*C.* spp.	US: UT	50		Water, drinking	(*28*)
2008	*C. jejuni*	US: WV	8		Water, drinking	(*28*)
2008	*C.* spp.	Australia	2		Chicken	(*67*)
2008	*C.* spp.	Australia	4		Chicken	(*67*)
2008	*C.* spp.	Australia	4		Chicken liver pâté	(*67*)
2008	*C.* spp.	Australia	6		Chicken	(*68*)
2008	*C.jejuni*; *norovirus*	Switzerland	126		Water, drinking	(*22*)
2008	*C. jejuni*	US: RI	4	3	Chicken	(*31*)
2008	*C. jejuni*	US: NC	8	2	Chicken, BBQ	(*31*)
2008	*C. jejuni*	US: NY	268	7	Clams, raw and steamed	(*31*)
2008	*C. jejuni*	US: CO	5	1	Lettuce, homegrown	(*31*)
2008	*C. jejuni*	US: AK	132	5	Peas, green	(*47*)
2008	*C.* spp.	US: MI	27	0	Pork	(*31*)
2008	*C.* spp.	US: OR	10	0	Cheese: queso fresco	(*31*)

Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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2008	*C. jejuni*	US: OH	3		Milk, raw	(*31*)
2008	*C. jejuni*	US: MA	8	0	Milk, raw	(*31*)
2008	*C.* spp.	US: MN	2	0	Milk, raw	(*31*)
2008	*C. jejuni*	US: MN	2	2	Milk, raw	(*31*)
2008	*C. jejuni*	US: PA	65	1	Milk, raw	(*31*)
2008	*C. jejuni*	US: UT	4	0	Milk, raw	(*31*)
2008	*C. coli*	US: ID	5		Milk, raw	(*31*)
2008	*C. jejuni*	US: CA	16		Milk, raw	(*31*)
2008	*C. jejuni*	US: ND	3	0	Milk, raw	(*31*)
2008	*C. jejuni*	US: TN	4	0	Milk, raw; water	(*31*)
2008	*C. jejuni*	US: WI	76	0	Beef, roast	(*31*)
2008	*C. jejuni*	US: FL	2		Chicken sandwich	(*31*)
2008	*C. jejuni*	US: WA	4	1	Turkey	(*31*)
2009	*C. jejuni*	Greece	60		Water, drinking	(*97*)
2009	*C. jejuni*	Korea	92		Chicken	(*179*)
2009	*C. jejuni*	Norway	12		Animal contact: lambs	(*121*)
2009	*C.* spp.	UK	59		Chicken liver pâté	(*171*)
2009	*C. jejuni*	US: MN	11	2	Lettuce	(*31*)
2009	*C. jejuni*	US: PA	9	1	Milk, whole, raw	(*31*)
2009	*C. jejuni*	US: PA	2	0	Milk, whole, raw	(*31*)
2009	*C. jejuni*	US: WI	52	1	Milk, whole, raw	(*31*)
2009	*C. jejuni*	US: CO	81	1	Milk, whole, raw	(*31*)
2009	*C. jejuni*	US: GA	11	0	Potato salad	(*31*)
2009	*C. jejuni*	US: UT	10	0	Cheese: queso fresco, raw	(*31*)
2009	*C. jejuni*	US: MA	70	2	Food, unknown	(*31*)
2009	*C.* spp.	Australia	4	0	Beef steak, salad	(*69*)
2009	*C.* spp.	Australia	35	0	Chicken liver parfait	(*69*)
2009	*C. jejuni*	US: AL	11		Water, river	(*80*)
2009	*C.* spp.; *Giardia*	US: ID	7		Water, drinking	(*80*)
2010	*C.* spp.	US: MO	67		Water, drinking	(*80*)
2010	*C. jejuni*	US: ID	3		Water, river	(*80*)
2010	*C. jejuni*	US: MO	16		Water, drinking	(*80*)
2010	*C. jejuni*	US: MT	101		Water, drinking	(*80*)
2010	*C. jejuni*; *Cryptosporidium*	US: PA	10		Water, drinking	(*80*)
2010	*C. jejuni*	US: UT	628		Water, drinking	(*80*)
2010	*C.* spp.	UK	24		Chicken liver parfait	(*87*)
2010	*C.* spp.	Scotland	18		Chicken, haggis terrine	(*154*)
2010	*C. jejuni*	Denmark	409		Water, drinking	(*73*)
2010	*C. jejuni*; *E. coli*; *Giardia*	Denmark	351		Water, recreational exposure	(*74*)
2010	*C.* spp.; *E. coli*	US: TN	6	1	Chicken, BBQ; sausage	(*31*)
2010	*C. jejuni*	US: FL	19	0	Broccoli; coleslaw; gravy	(*31*)
2010	*C. jejuni*	US: CO	3	0	Cheese curds	(*31*)
2010	*C.* spp.	US: AZ	15	1	Cheese, raw milk; milk, raw	(*31*)
2010	*C. jejuni*	US: PA	10	0	Chicken	(*31*)
2010	*C. jejuni*	US: NY	68	2	Clams, raw	(*31*)
2010	*C. jejuni*; STEC	US: CO	30	2	Milk, goat, raw	(*31*)
2010	*C. jejuni*	US: CO	2	0	Beef liver	(*31*)
2010	*C. jejuni*	US: MI	25	0	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: PA	22	3	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: MA	2	1	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: MI	11	0	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: VT	6	0	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: PA	4	1	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: SC	7	0	Milk, whole, raw	(*31*)
2010	*C. jejuni*	US: VT	11	0	Milk, whole, raw	(*31*)
2010	*C. jejuni*; *C. parvum*	US: MN	7	0	Milk, whole, raw	(*31*)

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2010	*C. jejuni*	US: NY	20	1	Milk, raw	(*31*)
2010	*C. jejuni*	US: IL	2	0	Milk, raw	(*31*)
2010	*C. jejuni*	US: ND	7	0	Milk, whole, raw	(*31*)
2010	*C.* spp.	Australia	15	1	Food, unknown	(*71*)
2010	*C. jejuni*	Australia	10	0	Chicken	(*71*)
2010	*C. jejuni*	Australia	18	2	Chicken liver pâté	(*71*)
2010	*C. jejuni*	Australia	17	1	Food, unknown	(*71*)
2010	*C. jejuni*	Australia	23	1	Food, unknown	(*71*)
2010	*C. jejuni*	Australia	5	0	Chicken	(*71*)
2010	*C. jejuni*; *Giardia*; norovirus; rotavirus	Belgium	222		Water, drinking	(*181*)
2010–2011	*C. coli*	Canada	10		Person-to-person (sexual)	(*48*)
2011	*C. jejuni*	US: TX; Mexico	26		Water, drinking	(*90*)
2011	*C.* spp.	UK	18		Duck liver pâté	(*2*)
2011	*C. jejuni*	US: AK	11		Milk, raw	(*30*)
2011	*C. jejuni*	US: WY	2	0	Animal contact: sheep	(*168*)
2011	*C.* spp.	UK	11		Chicken liver	(*42*)
2011	*C. jejuni*; *C. coli*	UK	49		Chicken liver pâté	(*37*)
2011	*C. jejuni*	US: WA	4	0	Chicken	(*31*)
2011	*C.* spp.	US: OH	2	0	Milk, goat, raw	(*31*)
2011	*C. jejuni*	US: KS	18	0	Milk	(*31*)
2011	*C. jejuni*	US: PA	3	0	Milk, whole, raw	(*31*)
2011	*C.* spp.	US: PA	5	0	Milk, whole, raw	(*31*)
2011	*C. coli*	US: MN	3	2	Milk, whole, raw	(*31*)
2011	*C. jejuni*	US: MN	2	0	Milk, whole, raw	(*31*)
2011	*C. jejuni*	US: SC	10	2	Milk, whole, raw	(*31*)
2011	*C. coli*	US: NC	3		Milk, whole, raw	(*31*)
2011	*C. jejuni*	US: CT	3	0	Octopus	(*31*)
2011	*C.* spp.; *Vibrio* spp.; *Vibrio cholerae*	US: MA	4	1	Oysters, raw	(*31*)
2011	*C. jejuni*	US: SC	23	1	Milk, raw	(*31*)
2011	*C.* spp.	US: MI	2	0	Milk, raw	(*31*)
2011	*C. jejuni*	US: NY	4	0	Milk, raw	(*31*)
2011	*C. jejuni*	US: NY	3	0	Milk, raw	(*31*)
2011	*C. jejuni*	US: NY	13	0	Milk, raw	(*31*)
2011	*C.* spp.	US: VA	8	1	Turkey; stuffing	(*31*)
2011	*C. jejuni*	US: WI	16	1	Milk, whole, raw	(*31*)
2011	*C.* spp.	New Zealand	5		Chicken liver pâté	(*110*)
2011	*C.* spp.	New Zealand	3		Lamb’s fry	(*110*)
2011	*C.* spp.	New Zealand	2		Lamb’s fry	(*110*)
2011	*C.* spp.	New Zealand	9		Chicken liver mousse	(*110*)
2011	*C.* spp.	New Zealand	4		Milk, raw	(*110*)
2011	*C.* spp.	New Zealand	8		Milk, raw	(*110*)
2011	*C. jejuni*	Australia	4		Chicken kebabs	(*57*)
2011	*C. jejuni*	Australia	22	1	Water, drinking	(*70*)
2012	*C.* spp.	Scotland	27		Water, drinking	(*152*)
2012	*C.* spp.	Australia	15	1	Chicken liver pâté	(*132*)
2012	*C. spp*	Australia	7	0	Chicken liver pâté	(*130*)
2012	*C.* spp.	Australia	4	0	Chicken liver pâté	(*130*)
2012	*C. jejuni*	Australia	2	1	Foods, Chinese	(*72*)
2012	*C. jejuni*	New Zealand	138		Water, drinking (est. total cases 828–1987)	(*149*)
2012	*C. jejuni*; *C. coli*	UK	45		Duck liver pâté	(*178*)
2012	*C. coli*	US: NV	22	1	Water, muddy surface	(*180*)
2012	*C. jejuni*	US: NY	6	2	Milk, whole, raw	(*31*)
2012	*C.* other	US: PA	2	0	Milk, whole, raw	(*31*)
2012	*C. jejuni*	US: CO	3	1	Liver	(*31*)
2012	*C. jejuni*	US: MN	7	0	Milk, whole, raw	(*31*)

2012	*C. jejuni*	US: OH	15	1	Strawberry dessert,; ground beef; tea	(*31*)
2012	*C. jejuni*	US: MD	11	2	Chicken liver pâté	(*31*)
2012	*C.* spp.	US: WA	5	0	Milk, whole, raw	(*31*)
2012	*C. jejuni*	US: PA	3	0	Milk, whole, raw	(*31*)
2012	*C.* unknown; *C. jejuni*	US: OH	51	2	Fruit salad	(*31*)
2012	*C.* spp.	US: TN	15	0	Salad	(*31*)
2012	*C. jejuni*	US: CA	11	0	Chicken	(*31*)
2012	*C. jejuni*	US: OH	2	0	Milk, whole, raw	(*31*)
2012	*C.* spp.	US: OH	4	0	Milk, whole, raw	(*31*)
2012	*C. jejuni*	US: UT	2	0	Cheese curds	(*31*)
2012	*C. jejuni*	US: OR	9	0	Chicken liver pâté	(*31*)
2012	*C. jejuni*	US: PA	10	0	Milk, whole, raw	(*31*)
2012	*C. jejuni*	US: CA	33	2	Milk	(*31*)
2012	*C. jejuni*	US: 3 states	6	1	Chicken, liver	(*165*)
2012	*C.* spp.	US: PA	4	0	Duck	(*31*)
2012	*C. jejuni*; *S. enterica*	US: WI	21	5	Beef intestine soup; beef, minced	(*31*)
2012	*C. jejuni*	US: 4 states	148	10	Milk, whole, raw	(*111*)
2013	*C. jejuni*	US: PA	8		Milk, raw	(*170*)
2013	*C. jejuni*	Australia	17	1	Duck liver parfait	(*81*)
2014	*C. jejuni*	US: WI	38		Milk, raw	(*190*)

**Some outbreaks with a small number of cases and no suspected vehicle were omitted from this chart.*

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Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu
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Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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Corresponding author: M. Ellin Doyle, Ph.D., medoyle@wisc.edu

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