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Campylobacter fetus Infections in Humans: Exposure and Disease

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Abstract

Campylobacter fetus can cause intestinal illness and, occasionally, severe systemic infections. Infections mainly affect persons at higher risk, including elderly and immunocompromised individuals and those with occupational exposure to infected animals. Outbreaks are infrequent but have provided insight into sources. Source attribution of sporadic cases through case-control interviews has not been reported. The reservoirs for *C. fetus* are mainly cattle and sheep. Products from these animals are suspected as sources for human infections. *Campylobacter fetus* is rarely isolated from food, albeit selective isolation methods used in food microbiology are not suited for its detection. We hypothesize that the general population is regularly exposed to *C. fetus* through foods of animal origin, cross-contaminated foodstuffs, and perhaps other, as yet unidentified, routes. *Campylobacter fetus* infection should be suspected particularly in patients with nonspecific febrile illness who are immunocompromised or who may have been occupationally exposed to ruminants.

Keywords

Campylobacter fetus ; food safety; exposure; immunocompromised

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Most *Campylobacter* infections present as diarrheal illness. However, in about 0.15% of cases, intestinal campylobacteriosis leads to bacteremia, often with infection involving distant organs [1]. The symptoms of such invasive campylobacteriosis will then vary with the affected organ. Although the majority (>90%) of cases of intestinal campylobacteriosis are caused by *Campylobacter jejuni* or *Campylobacter coli* [2], a small proportion is caused by *Campylobacter fetus*. In one Irish study, the DNA of *C. fetus* was detected in only 2.4% of cases of intestinal campylobacteriosis [3]. In contrast, *C. fetus* is the most commonly detected pathogen causing *Campylobacter* bacteriemia (19%–53%, dependent on the study) [4–6]. The fatality rate of such invasive *C. fetus* infections is reported at 14% [7]. Given the worldwide high incidence of campylobacteriosis, these data suggest that *C. fetus* infections are not uncommon and may constitute a public health issue. Nevertheless, relatively little is known about the infection sources and the people at risk. In this manuscript, we review the current knowledge of *C. fetus* infections in humans, the characteristics of those people who may be at risk, and the role of food as a potential source of infection.

CHARACTERISTICS OF *C. FETUS*

Campylobacter fetus is one of 24 currently recognized species within the genus *Campylobacter* (http://www.bacterio.cict.fr/c/campylobacter.html). It is a microaerophilic, gram-negative, spiral-shaped bacterium that grows between 25°C and 37°C. In contrast to the thermotolerant *C. jejuni* and *C. coli,* not all *C. fetus* isolates grow at 42°C. *Campylobacter fetus* comprises 2 subspecies: *C. fetus* subspecies *fetus* and *C. fetus* subspecies *venerealis*, which includes the biovar intermedius [8]. The subspecies are genetically very closely related but have different habitats.

To date, *C. fetus* has been most often recognized as an infectious agent of animals [9]. The primary reservoir of *C. fetus* subsp *fetus* is the gastrointestinal tracts of cattle and sheep; however, this subspecies can also be isolated from the feces of other animal species [8, 9]. In contrast, the natural niche of *C. fetus* subsp *venerealis* is the bovine genital tract, where it can cause infection in cows, resulting in infertility or abortion [10].

A newly proposed subspecies, *C. fetus* subsp *testudinum*, which has a specific association with reptiles, has also been isolated from ill humans [11], but is not considered further in this review.

CLINICAL PRESENTATION OF HUMAN *C. FETUS* INFECTION

The first documented human *C. fetus* infection, which in this case led to an abortion, was reported in 1947 [12]. In 1957, in the first systematic study, 19 cases of campylobacteriosis enabled differentiation between *Vibrio fetus* (now termed *C. fetus*) causing systemic illness and “related *Vibrio*” (now recognized as *C. jejuni* and *C. coli*) causing diarrheal disease [13].

The clinical signs of human *C. fetus* infection vary from an acute diarrheal illness to systemic illness [14, 15]. The presentations of the latter vary with the localization of the disseminated pathogen. Septicemia, with fever but without apparent localized infection, is reported in 24%–41% of cases [5, 7]. Other manifestations may be the result of neurological infections (meningitis, meningoencephalitis, subdural empyema, or brain

abscesses), osteomyelitis, lung abscesses, arthritis, and perinatal infections (eg, infection in utero, abortion, or placentitis) [15]. *Campylobacter fetus* infections may also cause vascular pathology (mycotic aneurysms, endocarditis, vasculitis, thrombophlebitis, or pericarditis).

Campylobacter fetus infections of pregnant women have been described from early stages in the pregnancy up to a full-term birth [16]. The clinical signs in the mother are fever, sometimes accompanied by diarrhea, but spontaneous abortions, without other clinical signs, have also been reported. In those cases in which living infants were born, many of those infants suffered from *C. fetus* sepsis, frequently leading to meningitis. In a study of 14 cases of infant *C. fetus* sepsis, 9 had a fatal outcome, underlining the severity of neonatal infections [16]. Perinatal infections are most often associated with a confirmed *C. fetus* infection in the mother [16].

Nearly all *C. fetus* infections in humans are reported to be caused by *C. fetus* subsp *fetus*. The few reported cases of *C. fetus* subsp *venerealis* involved isolates from vaginal discharges [17]. This parallels bovine infections where this subspecies colonizes the genital tract. However, subspecies identification is rarely performed by human clinical laboratories, and data on the ratio of *C. fetus* subsp *fetus* to *C. fetus* subsp *venerealis* in human isolates are limited. Identification of subspecies is recommended to obtain greater insights into the epidemiology of these infections [18].

INDIVIDUALS AT RISK FOR *C. FETUS* INFECTION

Several studies have shown that the majority (62%–74%) of patients with *C. fetus* bacteremia have a defined underlying disease [5, 7], indicating that the organism is mainly an opportunistic human pathogen. Predisposing factors for *C. fetus* infection include conditions that result in immunosuppression (eg, infection with human immunodeficiency virus [HIV], hematological malignancy, or splenectomy), cardiovascular disease with valve abnormalities, liver disease (eg, cirrhosis due to alcohol abuse), diabetes mellitus, and medical device implants. Elderly people and pregnant women, without any underlying disease, are also at risk [5, 16]. Some studies report an association between dental disease or tooth extraction in combination with raw meat consumption leading to *C. fetus* infection, suggesting a possible direct invasion route from the oral cavity [13, 19]. Systemic infections in healthy young hosts are rarely reported (Table 1), and such infections, when they occur, are generally associated with occupational contact with live animals or abattoir work, suggesting that such exposure increases the risk of infection. Prior treatment with antimicrobials has not been identified as a specific risk factor. However, as most patients have underlying disease, treatment with antimicrobials may be higher in this group compared with otherwise healthy patients. Demographic data on differences in the incidence of *C. fetus* infection between rural and urban areas are lacking.

PATHOGENESIS OF *C. FETUS* INFECTIONS IN HUMANS

Human *C. fetus* infection most likely begins with oral ingestion of the bacterium followed by intestinal colonization. Impaired gastric acidity may facilitate the passage through the stomach [31]. About 30% of colonized individuals develop diarrhea [1, 5, 31]. The

bacterial virulence factors that cause the diarrhea have not yet been identified. Clearly some individuals develop diarrhea and *C. fetus*–positive stools without clinical signs of systemic disease [23], suggesting that the infection can be limited to the intestinal tract. The incidental isolation or detection of DNA of *C. fetus* from stools of healthy people, in some cases contacts of *C. fetus* patients, indicates that intestinal colonization may also occur without diarrhea [23, 32]. The limited ability of *C. fetus* to breach the host defenses in otherwise healthy individuals may explain why dissemination of infection is mainly observed in immunocompromised or preconditioned individuals. The role of immunity in *C. fetus* infections is complex. Clearly, individual immunocompetence is very important. The underlying diseases that constitute risk factors include those specifically involving compromised cell-mediated (eg, HIV) and humoral (eg, hypogammaglobulinemia) immunity, indicating that both major arms of the acquired immune system are required for resistance to infection [7, 33]. In addition, the organism has evolved specific mechanisms to evade both host innate and adaptive immunity, which may enable the establishment and persistence of infection (see discussion of S-layer proteins below). The role of other *C. fetus* virulence-related genes is largely unexplored. For example, *C. fetus* clearly demonstrates a preference for endovascular surfaces and is associated with thrombosis, but the presence of virulence factors, such as heparinases, that may be involved has yet to be described. With whole-genome sequence analysis of 22 *C. fetus* strains, considerable variation in genomic content was identified, including in putative virulence-related genes [34]. Differences in the gene content of strains might contribute to differences in the clinical outcome of infections.

RELAPSING AND PERSISTENT *C. FETUS* INFECTIONS

Invasive *C. fetus* infections may relapse or persist from 20 days to 7 years after the initial diagnosis [24, 35, 36]. The frequency of relapse and its possible relationship with septic thrombosis have not been systematically investigated. The persistence of infection may reflect the presence of adaptive mechanisms in *C. fetus* that aid bacterial survival in the bloodstream and enable evasion of the host immune system. These mechanisms are based on characteristics of a surface layer (S-layer), which forms a capsule-like structure comprised of an array of S-layer proteins (SLPs).

The S-layer confers resistance to complement-mediated killing by preventing the binding of antibodies and the complement component C3b to the bacterial surface [37]. This inhibits phagocytosis and the subsequent killing of the bacterium by phagocytic cells during the acute phase of the infection, before the acquisition of adaptive responses.

The S-layer proteins also exhibit antigenic variation. This antigenic variation is based on DNA recombination of a family of SLP-encoding genes (*sap* genes), generating a range of protein variants with different antigenic properties [38]. The resulting continuous switching of the antigenic properties of the surface coat of the bacterium, first demonstrated during ovine abortion [39], enables evasion from generated SLP-specific antibodies. The relative “invisibility” to important innate mechanisms involved in serum and phagocytosis resistance, as well as its ability to alter surface structures recognized by adaptive immunity, provides an explanation for the repeated *C. fetus* isolations from patients with relapsing infections [36]. As in bovine and ovine infections, genetic and protein variation in patients

with relapsing infection has been defined [36, 39, 40]. *Campylobacter fetus* is an accidental pathogen of humans, unlike ungulates to which it has evolved. Its intrinsic mechanisms for avoiding host immunity are not sufficient per se for causing human infections, but the combination of its immune avoidance and the presence of host immunodeficiencies can be sufficient for the establishment of infection and multiple relapses.

DIAGNOSIS OF *C. FETUS* INFECTIONS IN HUMANS

As the clinical manifestations of invasive *C. fetus* infections are diverse, diagnosis remains a challenge. A key factor is the awareness that the pathogen may be the cause of intestinal disease as well as of severe or relapsing febrile illness. Diagnosis requires bacterial culture using appropriate culture methods. *Campylobacter* species are fastidious microorganisms that require microaerobic growth conditions. Isolation from stool samples may require selective media with antimicrobial supplements or, alternatively, a filter technique in combination with nonselective media. Diagnostics for *Campylobacter* in human stools usually focus on *C. jejuni* and *C. coli*. The incubation temperature of 42°C, which is often routinely used to isolate these *Campylobacter* species, precludes the recovery of at least 20% of *C. fetus* isolates that do not grow at this temperature (Dr C. Fitzgerald, US Centers for Disease Control and Prevention, personal communication). Similarly, the use of cefoperazone- or cephalothin-containing media, for the selective isolation of *C. jejuni* and *C. coli*, inhibits growth of *C. fetus* [31]. However, even with optimal culture methods, 2 large studies on diarrheal stool samples, using the nonselective filter method and incubation at appropriate atmosphere and temperature, did not detect *C. fetus* in 1980 and 1376 analyzed samples from the Netherlands and Denmark, respectively [41, 42]. In contrast, in a recent Irish study using molecular techniques, 8 of 7194 diarrheal stool samples tested positive for *C. fetus* DNA [3]. The difference in prevalence between these studies may be explained by a higher sensitivity of the molecular assay compared with culture, or by geographical differences. These studies indicate the prevalence of *C. fetus* as between 0% and 0.1% compared with 3%–8% for *C. jejuni*/*C. coli* [3, 41, 42]. Currently available culture-independent enzyme immunoassay–based diagnostic tests for *Campylobacter* in human stools will detect *C. jejuni* and *C. coli*, but not *C. fetus*.

Samples from extraintestinal infections, for example, blood or cerebrospinal fluid, will have fewer contaminating organisms, which may allow detection at a permissive temperature and using a microaerobic atmosphere without the use of selective media. Samples from extraintestinal infections that have an increased risk of contaminants (eg, bronchoscopy samples) should be cultured on selective media. The routine blood culture methods used in clinical microbiology should allow *C. fetus* growth; however, the efficacy of recovery from such approaches is unknown [43].

Once a suspected *C. fetus* isolate is obtained, phenotypic or molecular methods can be used to confirm the species. Reliable subspecies identification requires molecular analysis [8]; subspecies differentiation has no direct clinical relevance but might support a better understanding of the epidemiology.

RESERVOIRS OF *C. FETUS*

The sources for, and routes of, transmission of *C. fetus* to humans remain uncertain. The organism is mostly recognized as a veterinary pathogen causing fertility problems in cattle and sheep. A study of *C. fetus* antibodies in sheep in New Zealand showed that 48% of animals and 89% of flocks were positive [44]. Similarly, *C. fetus* was isolated from 9.5% of cattle fecal pats in the United Kingdom [9]. Such carriage in livestock can obviously constitute a potential source of human infection.

Unlike for *C. jejuni/C. coli*, poultry and pigs are not considered to be a source of *C. fetus*. In an experimental model, poultry appeared not to be susceptible to *C. fetus* [45], which probably reflects the hostile body temperature of birds for the organism. One study on turkeys reported that only 1 of 988 *Campylobacter* strains isolated was *C. fetus* [46]. In a 2-year study on *Campylobacter* in turkeys in Denmark, not a single *C. fetus* isolate was found (Dr B. Borck, Danish Technical University, personal communication).

It seems reasonable to assume that *C. fetus* is frequently shed, via animal feces, into the environment. Specific data are lacking on the extent of survival of *C. fetus* in manure and surface waters. Such surface waters could be contaminated by runoff from cattle fields and may be used in the irrigation of food crops. Extrapolation of data from *C. jejuni* and *C. coli* suggests that survival may be up to 10 months in cattle manure [47]. However, the survival profile of *C. fetus* subsp *fetus* is apparently quite different from that of the thermotolerant *Campylobacter* species [48], so such an extrapolation must be done with care. The level of exposure of humans from environmental sources cannot be reliably estimated.

CAMPYLOBACTER FETUS IN THE FOOD CHAIN AND SOURCE ATTRIBUTION

Food products from cattle and sheep are the most likely routes of transmission. Several studies report *C. fetus* contamination of food items (Table 2), mainly of liver and, to a lesser extent, red meat products. However, quantitative data on the *C. fetus* counts and on the effect of storage are not available, limiting risk assessment of exposure to the consumer. In food microbiology, the focus is on the detection of *C. jejuni* and *C. coli* and, once again, the choice of media and incubation temperature are not optimal for the detection of *C. fetus*. Depending on the procedure, there might be a selection for cephalosporin-resistant strains that grow at 42°C. Therefore, there may be underdetection of *C. fetus* in food samples.

Most liver and meat products are cooked before consumption and, therefore, would not pose a risk for humans. Nevertheless, a small fraction of meat and liver is consumed not fully cooked, or even raw, and once *Campylobacter* arrives in the kitchen there is a risk of cross-contamination to other foodstuffs that are consumed without further processing. Raw milk is a well-documented source of human *C. jejuni* infections and might also act as a potential vehicle for *C. fetus* [14]. As there are no surveillance systems implemented for *C. fetus* infections, a possible higher incidence in those countries that allow the retail of unpasteurized milk products cannot be identified. Cheese has been implicated in an

outbreak [56]. *Campylobacter fetus* has also been isolated from vegetables in one study from Malaysia [52].

Evidence that contaminated food may be a source of human *C. fetus* infection comes from epidemiological investigations of outbreaks and sporadic *C. fetus* illnesses. There is no direct evidence of food samples being the cause of *C. fetus* infection. However, in one unusual outbreak, 10 clinic-based patients, all with severe underlying illness, acquired *C. fetus* infection. They developed bacteremia and one patient died. All 10 had consumed raw calf liver, fresh fruit, and vegetable juices from a nutritional therapy clinic in Mexico [57]. Unfortunately, the food items were not available for culture. In addition, a milk-borne outbreak with both *C. jejuni* and *C. fetus* infections has been described, in which individuals, consuming raw cow's milk intended for horses, developed gastroenteritis with one or the other pathogen, supporting the likely role of raw milk as the vehicle [14]. In another outbreak in a nursing home in Ohio, 13 of 220 residents were infected with *C. fetus* [56]. Commercial cottage cheese from one dairy was strongly implicated epidemiologically as the source, and the dairy was noted to be experiencing quality problems at the time, although cultures of cheese produced 2 months later did not yield the organism [56]. In several sporadic cases, various foods have been suspected as the source, although *C. fetus* has not been isolated from these food items. Two outbreaks in neonatal care units, involving 4 cases in each unit, were described after the birth of an infected neonate [32, 58], suggestive of human-to-human transmission. These observations highlight the importance of routine hygienic measures to prevent transmission within facilities housing people at risk.

Source attribution of human disease can generally be performed by microbiological or epidemiological approaches. For *C. jejuni*, multilocus sequence typing (MLST) has been used successfully for the microbiological source attribution of human disease [59]. For *C. fetus*, an MLST scheme also is available, but the limited genetic diversity in this species may hamper source attribution studies using this approach. Source attribution by epidemiological methods (eg, a case-control study of sporadic cases) has not been reported for *C. fetus*.

EXPOSURE OF THE GENERAL POPULATION TO *C. FETUS*

The presence of *C. fetus* in liver and meat from swine and cattle suggests that the general population may be repeatedly exposed to viable organisms. This parallels the epidemiology of *C. jejuni* for which serological surveys and risk assessment studies suggest that exposure is common, although only a fraction of the population becomes ill [60]. Recent studies on *C. jejuni* suggest a considerable role for non–poultry meat transmission routes [61]. These alternative, as yet unidentified, routes should also be considered for *C. fetus*. Examples of such routes include contact with contaminated surface water or surface-watered crops. However, there is currently no evidence of asymptomatic *C. fetus* carriage in the general population.

The sporadic *C. fetus* infections in seemingly healthy individuals who have occupational exposure (Table 1) suggest that infection depends on both infective dose and the immune status of the individual. When immune status becomes impaired, protection decreases and the risk for contracting illness might increase after (even relatively low) exposure through

food or other routes. In contrast, when occupational exposure involves a high dose, even a healthy immune system may be overwhelmed. However, the development of immunity due to chronic exposure may limit the risk in such individuals. The development of tools to measure specific immunity against *C. fetus* is needed to establish the immune status of the general population and of heavily exposed individuals such as sheep farmers.

CONCLUSIONS

Campylobacter fetus infection in humans is rare, but is often invasive and is sometimes fatal. *Campylobacter fetus* infection should be suspected particularly in those patients with nonspecific febrile illness, those who may have been occupationally at risk, or those who are immunocompromised by underlying diseases that affect their innate or acquired, humoral or cellular immune status. There is no evidence for underdetection of *C. fetus* in stools from diarrheal patients, but laboratory diagnosis tends to be carried out with selective culture conditions that inhibit the growth of *C. fetus*. A seroepidemiological study may complement these findings and correct for possible misdiagnosis, but this awaits development of a *C. fetus*–specific seroassay. *Campylobacter fetus* infection appears to be primarily zoonotic, with sheep and cattle as major reservoirs. Direct animal contact is an important route, especially for some professions, such as farming or veterinary work. We hypothesize that humans are exposed to *C. fetus* through contaminated bovine and ovine products, particularly liver. Following this exposure, mainly immunocompromised individuals are at risk of becoming clinically ill. Exposure assessment studies await appropriate detection of *C. fetus* in food items. A systematic study on environmental samples using appropriate culture and molecular analysis tools will provide essential information to assess the environmental risks of human infection. Human-to-human transmission of *C. fetus* is suggested to occur among highly susceptible neonates and urges implementation of strict hygienic measures.

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Table 1.

Sporadic Cases of *Campylobacter fetus* Infections

Case	Sex/Age, y	Previous Health Status	Likely Exposure	Clinical Signs and Origin of Isolate	Microbiological Results	Reference
1	Male	No specific remarks on the health status, but no visit of physician was reported	Occupational; laboratory worker engaged in the study of *C. fetus*	Isolated from pustule on the cheek	Phenotypically most likely *C. fetus*	Ward, 1948 [20]
2	Male/39	Healthy	Occupational; livestock trucker	Cough, abdominal discomfort, fever. Isolated from blood	*C. fetus*	King, 1957 [13]
3	Male/31	Healthy	Occupational; butcher in abattoir	Cough, nausea, diarrhea, blurred vision, dizzy, fever, chills, headache, enlarged lymph nodes. Isolated from blood	*C. fetus*	King, 1957 [13]
4	Male/53	Impared fasting glucose but otherwise healthy	Occupational; farmer	6-day acute febrile illness. Isolated from blood and bone marrow aspirate	*C. fetus* subsp *fetus*	Zonios et al, 2005 [21]
5	Male/40	No health problems reported	Occupational; farmer	Meningitis, headache, fever. Isolated from cerebrospinal fluid	*C. fetus* subsp *fetus*	Gubina et al, 1976 [22]
6	Several members of Hutterite colony (average age 21.8)	No health problems reported	Working in abattoir was identified as risk factor; consumption of raw milk and cheese; unchlorinated water	Diarrhea (7 isolates from 15 stool samples)	*C. fetus* subsp *fetus*	Rennie et al, 1994 [23]
7	Male/54	No past medical problems	Occupational; slaughterhouse worker	Pleuritic chest pain, lethargy, fever. Isolated from blood	*C. fetus* subsp *fetus*	Ganeshram et al, 2000 [24]
8	Male/65	Heart problems, infected residual teeth	Occupational; farmer	Fever, chills, weight loss, enlarged spleen, diarrhea. Isolated from blood	*C. fetus*	King, 1957 [13]
9	Male/40	Brucellosis	Occupational; abattoir worker	Diarrhea, fever, chills, headache. Isolated from blood	*C. fetus*	King, 1957 [13]
10	Male/48	Previous alcohol overuse	Occupational; abattoir worker	Fever, endocarditis. Isolated from blood	*C. fetus* subsp *fetus*	Wong et al, 2003 [25]
11	Male/46	Chronic alcoholism, malnutrition	Occupational; farmer	Coughing, gastrointestinal problems, headaches. Isolated from blood	*C. fetus* subsp *fetus*	Gubina et al, 1976 [22]
12[a]	Male/62	Postnecrotic cirrhosis, possible liver transplantation	Exposure to diseased calves	Cellulitis, fever	*C. fetus* subsp *fetus*	Nadir et al, 1994 [26]
13	Male/75	Healthy	Frequent consumption of smoked sheep cheese from unpasteurized milk	Undulating fever, abscesses upper jaw. Isolated from blood	*C. fetus* subsp *fetus* and *C. lari*	Krause et al, 2002 [27]
14	2 male/1 and 7; 1 female/5	Healthy	Milk consumption	Diarrhea. Isolated from stool	*C. fetus* subsp *fetus*	Klein et al, 1986 [14]
15	Male/28	Healthy	Khat chewing	Fever, diarrhea, headache, photophobia. Isolated from blood	*C. fetus* subsp *fetus*	Martinez-Balzano et al, 2013 [28]
16	Male/37	Healthy	Unknown	Fever, low back pain, Pyogenic spondylodiscitis. Isolated from blood	*C. fetus*	Tanaka et al, 2012 [29]

Cases reported in previously healthy persons who were occupationally exposed (cases 1–7), persons with other illnesses who were occupationally exposed (cases 8–12), and previously healthy persons who were not occupationally exposed (cases 13–16). Cases in pregnant women are excluded. One additional healthy case has been reported in the literature [30], but this publication was followed by a discussion in the same journal and the apparently healthy status was questioned.

[a]This case was reported as a patient who showed no overt evidence of immune incompetence, but the clinical description suggested that this patient did not fit in the group of previously healthy individuals.

Table 2.

Campylobacter fetus Isolated From Food Items[a,b]

Product	Animal Species	Prevalence	Method(s)	Country	Reference
Liver and bile	Cattle	45% (bile) and 5% (liver); 50% isolates *C. fetus*[c]	Preston enrichment; mCCDA plates	Japan	Enokimoto et al, 2007 [49]
Liver	Lamb	2.1%	Preston enrichment; direct plating from enrichment: mCCDA	UK	Kramer et al, 2000 [50]
Liver	Cattle	12.5%	Preston enrichment; direct plating from enrichment: mCCDA	UK	Kramer et al, 2000 [50]
Liver	Pig	3%	Preston enrichment; direct plating from enrichment: mCCDA	UK	Kramer et al, 2000 [50]
Carcass at slaughter	Turkey	<1% (publication does not give exact percentage; probably 1 isolate of 988 strains)	Preston enrichment; CCDA	US	Logue et al, 2003 [46]
Meat	Lamb	12/90 isolates	Bolton enrichment; CCDA	UK	Little et al, 2008 [51]
Meat	Pork	1/68 isolates	Bolton enrichment; CCDA	UK	Little et al, 2008 [51]
Vegetables		1.9% from 1 shop	Bolton enrichment; CCDA plating	Malaysia	Chai et al, 2007 [52]
Milk (filter)	Dairy cattle	1/196 inline filters	Bolton enrichment; CCDA, Preston, Skirrow plating	Italy	Serraino et al, 2012 [53]

[a]One *Campylobacter fetus* subsp *fetus* isolate was reported by Kuana et al [54] from broilers, but there was uncertainty about the correct identification of the species.

[b]One study from Germany [55] reported 29.2% prevalence of "presumptive *C. fetus*" in turkey meat. Identification could not be confirmed as strains were not available (G. Klein, Tierärztliche Hochschule Hannover, personal communication).

[c]Quantitatively: $\log_{10}$ 3–7 colony-forming units (CFU)/mL bile and $\log_{10}$ 1–2 CFU/g liver.