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Features of illnesses caused by five species of *Campylobacter*, Foodborne Diseases Active Surveillance Network (FoodNet) – 2010–2015

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SUMMARY

The Foodborne Diseases Active Surveillance Network (FoodNet) conducts population-based surveillance for *Campylobacter* infection. For 2010 through 2015, we compared patients with *Campylobacter jejuni* with patients with infections caused by other *Campylobacter* species. *Campylobacter coli* patients were more often >40 years of age (OR = 1·4), Asian (OR = 2·3), or Black (OR = 1·7), and more likely to live in an urban area (OR = 1·2), report international travel (OR = 1·5), and have infection in autumn or winter (OR = 1·2). *Campylobacter upsaliensis* patients were more likely female (OR = 1·6), Hispanic (OR = 1·6), have a blood isolate (OR = 2·8), and have an infection in autumn or winter (OR = 1·7). *Campylobacter lari* patients were more likely to be >40 years of age (OR = 2·9) and have an infection in autumn or winter (OR = 1·7). *Campylobacter fetus* patients were more likely male (OR = 3·1), hospitalized (OR = 3·5), and have a blood isolate (OR = 44·1). International travel was associated with antimicrobial-resistant *C. jejuni* (OR = 12·5) and *C. coli* (OR = 12) infections. Species-level data are useful in understanding epidemiology, sources, and resistance of infections.

Key words: Campylobacter, food-borne infections, surveillance.

INTRODUCTION

Campylobacter causes an estimated 1·3 million illnesses in the USA each year [1]. Antimicrobial resistance in this pathogen is a serious concern [2]. There are currently 26 *Campylobacter* species; *Campylobacter jejuni* accounts for the majority (85–95%) of human infections, followed by *C. coli* (5–10%), and less commonly *C. upsaliensis*, *C. fetus*, *C. lari*, and other rare species [3].

Speciation is important in understanding the epidemiology of infection because *Campylobacter* organisms and their reservoirs are diverse. The primary reservoirs are poultry, cattle, and pigs; however, *Campylobacter* has been isolated from numerous other animal species and the environment, and the prevalence of different *Campylobacter* species in animals differs. For example, *C. coli* has been isolated more often than *C. jejuni* from swine and *C. jejuni* more often than *C. coli* from chicken [4]. *C. fetus* is

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primarily associated with cattle and sheep [5] but has also been identified in reptiles [6]. *C. upsaliensis* is frequently isolated from cats and dogs [7]. *C. lari* has been isolated from a variety of sources including wild birds, seawater, and shellfish [8]. Unpasteurized dairy products, poultry, and drinking water have been sources of *Campylobacter* outbreaks caused by various species [9]. Antimicrobial susceptibility patterns differ by species, with more erythromycin and ciprofloxacin resistance in *C. coli* isolates [4]. Differences in demographics of and risk factors for infection with various *Campylobacter* species have been described in patients in Europe [10, 11].

Few clinical laboratories in the USA routinely perform speciation beyond *C. jejuni*. Species-level identification of non-*C.jejuni* is challenging using phenotypic methods and it does not affect clinical treatment nor aid in outbreak detection. In addition, isolation methods are biased toward recovery of *C. jejuni*. Thus, *Campylobacter* surveillance data in the USA are typically presented at the genus level. To our knowledge, no comprehensive description of *Campylobacter* cases at the species level in the USA has been published. We attempt to fill this gap by describing available species-level data from 10 Foodborne Diseases Active Surveillance Network (FoodNet) sites, and comparing characteristics of patients and illnesses by the species causing infection.

METHODS

FoodNet is the foodborne disease component of the Centers for Disease Control and Prevention (CDC)'s Emerging Infections Program, a collaborative project of CDC, 10 state health departments, the United States Department of Agriculture's Food Safety and Inspection Service, and the Food and Drug Administration. Since 2004, the FoodNet catchment area has included the entire states of Connecticut, Georgia, Maryland, Minnesota, New Mexico, Oregon, and Tennessee and selected counties in California, Colorado, and New York. FoodNet conducts surveillance for human *Campylobacter* infections by routinely contacting clinical laboratories serving the catchment area to compile reports of all culture-confirmed infections. Staff collect patient demographics, hospitalization status, outcome, and specimen information from physicians, laboratory records, or through a patient interview in all sites. Information on international travel in the 7 days before illness onset is recorded from an interview or patient chart when available, and patients with such a history are considered to have travel-associated infections.

In some sites, isolates are sent from clinical laboratories to state public health laboratories (SPHLs) for confirmation and speciation. Between 2010 and 2015, Maryland, Minnesota, and New Mexico required all isolates to be submitted, and New York required submission of isolates from 15 of 34 FoodNet counties; routine submission was requested but not required in Georgia and Tennessee, and routine submission was neither requested nor required in California, Colorado, Connecticut, and Oregon. In addition, all sites forward some isolates to CDC for speciation and antimicrobial susceptibility testing as part of the National Antimicrobial Resistance Monitoring (NARMS) Program. Seven states selected *Campylobacter* isolates to forward based on a sampling scheme applied to isolates received at SPHLs: Georgia, Maryland, and New York (one forwarded for every two received), Minnesota (1:5), New Mexico (1:3), Oregon and Tennessee (all). In California, Colorado, and Connecticut, isolates are sampled from those received at the SPHL from one participating reference laboratory in each state. Because not all states require isolates to be submitted to the SPHL, the number of isolates sent to CDC is not consistently proportional to the total number of *Campylobacte*r infections reported to FoodNet.

Identification of *C. jejuni* was performed by the typical colony and Gram stain morphology, catalase, oxidase, growth at 42 °C, and the hippurate hydrolysis test. Hippurate-positive isolates were identified as *C. jejuni*. Isolates that were negative for hippurate hydrolysis were further tested with indoxyl acetate. Hippurate-negative isolates were also further characterized by polymerase chain reaction assays with species-specific targets for *C. jejuni* (*mapA* or *hipO* gene), *C. coli* (*ceuE* gene or *glyA* gene), *C. fetus* (*sapD* gene), or other species-specific primers [12]. *C. jejuni* and *C. coli* isolates were tested for antimicrobial susceptibility using standard NARMS methods [13]. Only resistance to quinolones (ciprofloxacin or nalidixic acid) and macrolides (azithromycin or erythromycin) is included in our analysis because these are the two most important classes for treatment.

We analyzed data from cases of *Campylobacter* infection reported to FoodNet from 2010 through 2015 that had species results available from a SPHL or CDC. Antimicrobial susceptibility information was available for 2010–2015 from a subset of *C. jejuni*

and *C. coli* isolates. We performed statistical analyses using SAS version 9.3 (SAS Institute, Cary, NC, USA). Incidence rates were calculated using US census data. *C. coli*, *C. lari*, *C. fetus*, and *C. upsaliensis* were individually compared with *C. jejuni* by age (median and in 5-year categories), sex, race, ethnicity, clinical symptoms, hospitalization, outcome, specimen source, international travel, season, and residence in a metro area. Fisher's exact tests were used to compare proportions. The criterion for significance was a 95% confidence interval (CI) excluding 1·0. All variables that showed significant associations were included in species-specific multivariable logistic regression models. Final models were developed using the stepwise option in Proc Logistic SAS Version 9.3. (SAS Institute, Cary, NC, USA). Seasons were defined as follows: winter (December–February), spring (March–May), summer (June–August), and autumn (September–November). FoodNet sites were grouped by US Census Region as follows: northeast (CT, NY); midwest (MN); south (GA, MD, TN); mountain (CO, NM); and Pacific (CA, OR). FoodNet counties were classified as urban, suburban, or rural based on USDA's Economic Research Service 2013 Rural–Urban Continuum Codes [14].

RESULTS

We identified 39 345 culture-confirmed *Campylobacter* infections in FoodNet sites from 2010 through 2015. We obtained species results for 16 549 (42%) of the isolates; 6971 (42%) were speciated at CDC, and 9578 (58%) were speciated at SPHLs. Forty-four percent of the results from SPHLs came from Minnesota. Of 16 549 isolates with species information, 14 672 (89%) were *C. jejuni*, 1404 (8%) were *C. coli*, 333 (2%) were *C. upsaliensis*, and 140 (1%) were other species, including *C. lari* (98), *C. fetus* (35), *Campylobacter hyointestinalis* (five), *Campylobacter curvus* (one), and *Campylobacter helveticus* (one). The percentage of non-*C. jejuni* species was relatively stable at 10% (259/2673) in 2010 and 12% (336/2784) in 2015.

Patient age and sex distributions varied across *Campylobacter* species (Fig. 1 and Table 1). Patients with *C. coli* infection tended to be older than *C. jejuni* patients but had a similar sex distribution, with about 56% of infections in males. *C. upsaliensis* patients tended to be younger – the proportion of patients <5 years old was higher than for any other species – and a higher percentage (58%) were female. Although few patients with *C. fetus* and *C. lari* infection were reported, their age and sex distribution showed patterns similar to but more pronounced than those of *C. coli*, with even higher median ages (50 and 57 years) and percentages of males (83%, 63%), respectively. The majority of persons with *Campylobacter* infection identified as white and non-Hispanic, but there were some racial and ethnic differences between patients infected with different species. Thirteen percent of persons with *C. fetus* cases were Black compared with 8% or less for other species. Nine percent of *C. fetus* and 6% of *C. coli* patients were Asian, compared with 5% or less for other species. Sixteen percent of *C. upsaliensis* patients were Hispanic, compared with 12% or less for other species.

Specimen source and patient outcome also varied by species, especially for *C. fetus*. The proportion of isolates from blood was highest (46%) for *C. fetus* infections, and over half of *C. fetus* patients were hospitalized, compared with $\leqslant$3% bloodstream isolations and $\leqslant$17% hospitalization for most other species.

C. jejuni and *C. coli* infections had similar regional distributions. A higher percentage of *C. upsaliensis* cases occurred in the Pacific region, *C. lari* cases in the south, and *C. fetus* cases in the midwest (Fig. 2). *C. jejuni* incidence rates were highest in rural areas for persons younger than 60 years and in suburban areas for persons 60 years and older (Fig. 3). *C. coli* rates were highest in rural areas for children <5 years, in suburban areas for persons aged 5–39 years, and in urban areas for persons 40 years and older. *C. upsaliensis* rates were highest in rural areas for children <5 years and persons over 60 years. These patterns persisted after excluding travel-associated cases.

C. jejuni and *C. coli* infections exhibited strong summer peaks; the peak in *C. coli* cases occurred slightly later than *C. jejuni*. *C. upsaliensis* and *C. lari* infections predominated in autumn and winter months (Fig. 4). International travel in the 7 days before illness onset was reported by 16% of persons with *Campylobacter* infection, most commonly among those with *C. coli* (22%) and rarely among those with *C. upsaliensis* (1%) infections (Table 1). Travel-associated *Campylobacter* infections showed little seasonality with the exception of a slight winter peak among *C. coli* cases (Fig. 4).

Data from patients with infections of the more common *Campylobacter* species were compared with data from *C. jejuni* patients in multivariate models

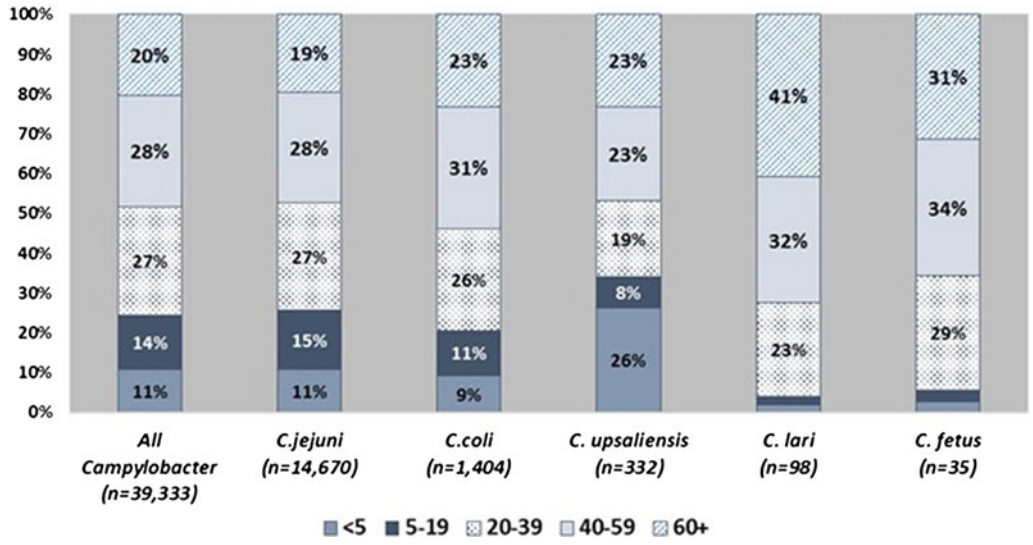

Fig. 1. Distribution of patients with *Campylobacter* infection, by age group and species – FoodNet, 2010–2015.

(Table 2). *C. coli* patients were more likely than *C. jejuni* patients to be older than 40 years, be Asian, be Black, have an infection in fall or winter, live in an urban area, and report international travel in the 7 days before infection; and less likely to be hospitalized. *C. upsaliensis* patients were more likely than *C. jejuni* patients to be female, be Hispanic, have an isolate from blood and infection in autumn or winter, and less likely to report international travel. *C. lari* patients were more likely than *C. jejuni* patients to be older than 40 years and have an infection in autumn or winter. *C. fetus* cases were more likely than *C. jejuni* cases to be male, hospitalized, and have an isolate from the blood.

Antimicrobial susceptibility information was available for 6010 *C. jejuni* and 665 *C. coli* isolates. Resistance to quinolones (35% *vs.* 24%) and macrolides (11% *vs.* 3%) was higher among *C. coli* isolates than *C. jejuni* isolates. Resistance among *C. jejuni* isolates was higher in the metro (27%) than in suburban and rural (15%) areas ($P < 0{\cdot}0001$). Among patients with *C. jejuni* infection, age >20 years (OR = 1·4; 95% CI 1·1–1·8), Asian race (OR = 2·3; 95% CI 1·4–3·9), and international travel in the 7 days before infection (OR = 12·5; 95% CI 10·0–15·7) was associated with any resistance. Among *C. coli* patients, international travel in the 7 days before infection (OR = 12; 95% CI 6·4–22·7) was associated with any resistance. Among travelers with either species, the highest percentage of resistant infections was found among persons who visited Asia (18/171 (91%)) or South America (17/83 (83%)).

DISCUSSION

Public health activities to control *Campylobacter* infections in the USA generally focus at the genus level; speciation of isolates is relatively unusual. Our analysis showed significant demographic and clinical differences between patients infected with different species highlighting the value of examining *Campylobacter* at the species level. The high burden of *Campylobacter* infection, its associated sequelae such as Guillain–Barré syndrome, and the potential for treatment failure due to antimicrobial resistance emphasize the urgency of improved control.

C. jejuni is the most common species and provides a good comparison group against which to examine characteristics of other species. In our data, patients with *C. jejuni* infection were predominately White and non-Hispanic, and a little over half were male. Less than a quarter of patients were hospitalized, and few had invasive infections. Rates of infection were highest in rural areas, particularly among children <5 years old, an association that has been well documented in other countries [15, 16]. *C. jejuni* infections overall showed a strong summer seasonality consistent with patterns described for other temperate countries [17]. It is well established that poultry is the primary risk factor for sporadic infections [18, 19]. Although poultry is eaten year-round, the seasonality of infections may be

Table 1. *Characteristics of* Campylobacter *patients, by five most common species – FoodNet, 2010–2015*

	C. jejuni (*N* = 14 672)		*C. coli* (*N* = 1404)		*C. upsaliensis* (*N* = 333)		*C. lari* (*N* = 98)		*C. fetus* (*N* = 35)		Other species (*N* = 7)		Total (*N* = 16 549)	
Characteristic	*n*/*N*	(%)	*n*/*N*	(%)	*n*/*N*	(%)	*n*/*N*	(%)	*n*/*N*	(%)	*n*/*N*	(%)	*n*/*N*	(%)
Sex														
Male	8043/14 661	(55)	785/1401	(56)	141/332	(42)	62/98	(63)	29/35	(83)	5/7	(71)	9065/16 534	(55)
Median age in years														
All (female; male)	37 (39; 36)		43 (42; 44)		37 (41; 23)		57 (46; 59)		50 (55; 49)		49 (61; 47)		38 (39; 37)	
Race														
Asian	364/12 939	(3)	77/1237	(6)	3/299	(1)	5/93	(5)	3/32	(9)	0/6	(0)	452/14 606	(3)
Black	628/12 939	(5)	96/1237	(8)	15/299	(5)	2/93	(2)	4/32	(13)	3/6	(50)	748/14 606	(5)
White	11 243/12 939	(87)	1001/1237	(81)	265/299	(89)	85/93	(91)	24/32	(75)	3/6	(50)	12 621/14 606	(86)
Other	704/12 939	(5)	63/1237	(5)	16/299	(5)	1/93	(1)	1/32	(3)	0/6	(0)	785/14 606	(5)
Ethnicity														
Hispanic	1485/12 682	(12)	131/1209	(11)	47/298	(16)	7/89	(8)	3/35	(9)	0/6	(0)	1673/14 319	(12)
Outcome														
Hospitalized	2482/14 401	(17)	207/1380	(15)	52/325	(16)	13/97	(13)	19/35	(54)	3/7	(43)	2776/16 245	(17)
Died	14/14 441	(0·1)	2/1379	(0·1)	0/327	(0)	0/97	(0)	0/35	(0)	0/7	(0)	16/16 286	(0·1)
Specimen source														
Blood	140/14 656	(1)	18/1402	(1)	11/332	(3)	2/96	(2)	16/35	(46)	0/7	(0)	187/16 528	(1)
International travel	1965/12 780	(15)	263/1197	(22)	3/284	(1)	6/84	(7)	2/31	(6)	0/5	(0)	2239/14 381	(16)
Live in an urban area	11 546/14 672	(79)	1178/1404	(84)	257/333	(77)	84/98	(86)	28/35	(80)	7/7	(100)	13 100/16 549	(79)
Occur in autumn or winter	5984/14 672	(41)	634/1404	(45)	177/333	(53)	53/98	(54)	15/35	(43)	2/7	(29)	6865/16 549	(41)

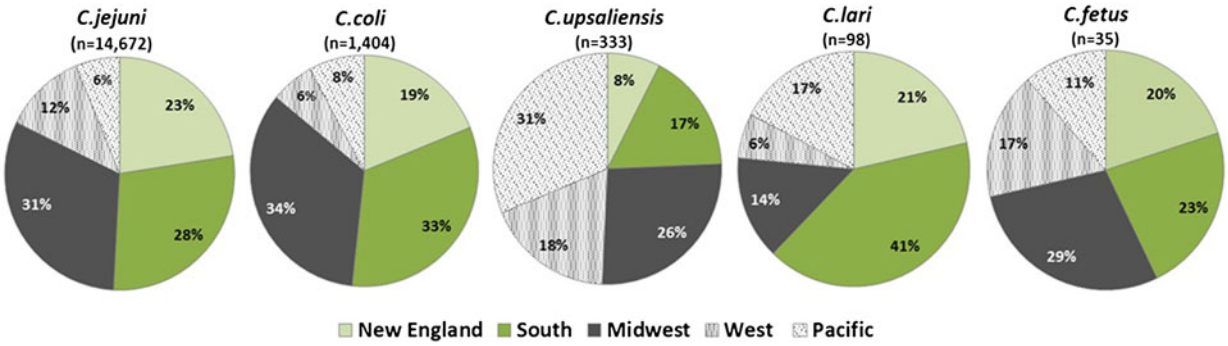

Fig. 2. Distribution of *Campylobacter* species by geographic region – FoodNet, 2010–2015.

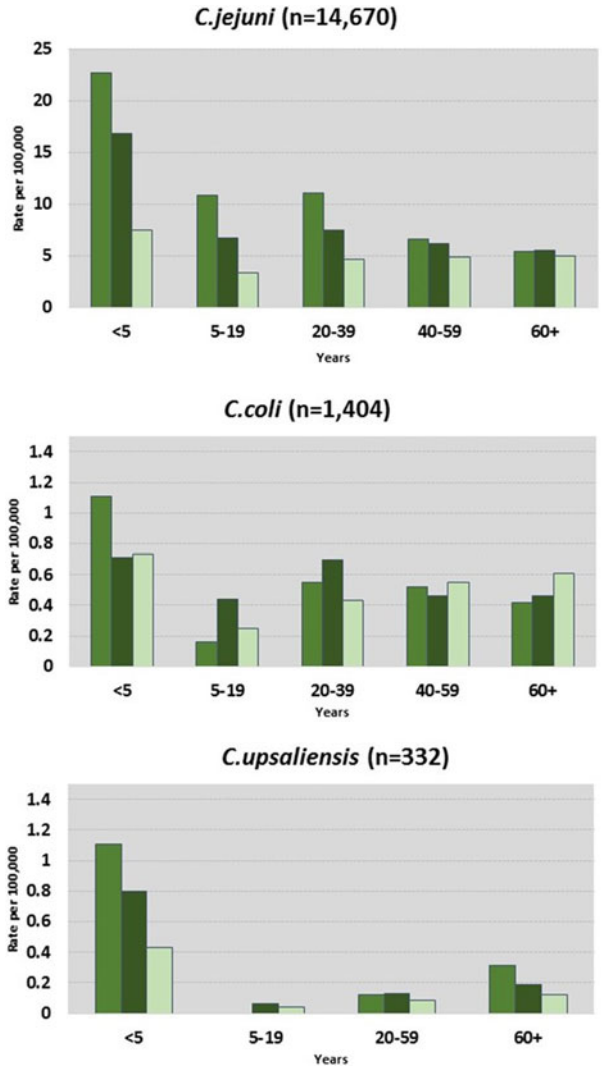

Fig. 3. *Campylobacter* infections by species, location, and age group – FoodNet, 2010–2015.

explained by studies that have shown that the prevalence of *Campylobacter* in broiler flocks and poultry at retail varies by season and is highest in warmer months [20, 21]. Exposure to other domestic risk factors common in summer months such as animal contact, raw milk consumption, swimming, eating barbeque-prepared meals, and drinking water from untreated sources likely also influence the summer peak [19, 22].

C. coli is the second most commonly identified species in the USA. Compared with *C. jejuni*, persons infected with *C. coli* were more often older than 40 years, Asian, or Black. Nearly a quarter of patients with *C. coli* reported international travel. Many of these differences are consistent with previous studies [10, 11, 23], but the association with Black race, to our knowledge, has not been previously reported. Mechanisms behind these differences are not known but could reflect occupational or environmental exposures, cultural practices, dietary preferences, or genetic predisposition. The use of proton pump inhibitors has been associated with *Campylobacter* infection [18, 24], and differential resistance to acid between the two species has been hypothesized to play a role in age differences [23]. *C. coli* infection has been associated with the consumption of pate and meat pies [10], bottled water [10], undercooked eggs [25], swimming [18], and contaminated surface water [26]. International travel might contribute to the higher rate of *C. coli* infections in winter months.

C. upsaliensis is the third most commonly identified species in the USA. Compared with *C. jejuni*, patients with *C. upsaliensis* infection were more often female and Hispanic. Of all the species we examined, *C. upsaliensis* infections were least likely to be travel-associated. Female gender has been associated with infection with specific *C. coli* and *C. jejuni* strain types found in poultry [27], possibly because women are more likely than men to prepare food, but it is unclear whether this explanation extends to other species. While *C. upsaliensis* has been isolated from foods such as ground beef [28], the infection has more often been associated with exposure to domestic pets such as dogs and cats. The association

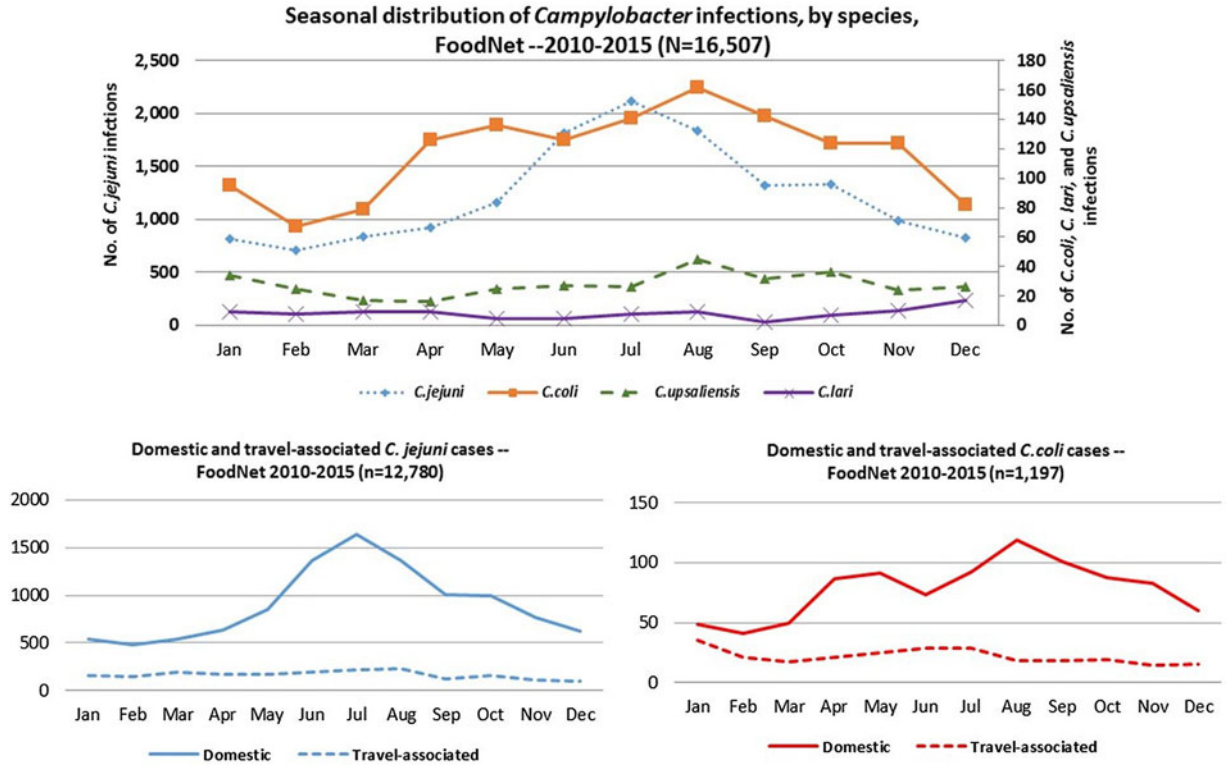

Fig. 4. Seasonal distribution of patients with *Campylobacter* infection by species, overall and by international travel history – FoodNet, 2010–2015.

Table 2. *Multivariate analysis of selected* Campylobacter *species compared with* Campylobacter jejuni*, FoodNet, 2010–2015*

	Campylobacter coli OR (95% CI)	*Campylobacter upsaliensis* OR (95% CI)	*Campylobacter lari* OR (95% CI)	*Campylobacter fetus* OR (95% CI)
Male	n/s	0·6 (0·5–0·8)	n/s	3·1 (1·3–7·7)
Age				
⩾40 (*vs.* <40 years)	1·4 (1·2–1·6)	n/s	2·9 (1·8–4·5)	n/s
Race				
Asian	2·3 (1·7–3·0)	n/s	n/s	n/s
Black	1·7 (1·3–2·2)			
White	Reference			
Ethnicity				
Hispanic	n/s	1·6 (1·1–2·2)	n/s	n/s
Hospitalized	0·8 (0·6–0·9)	n/s	n/s	3·5 (1·6–7·5)
Specimen from blood	n/s	2·8 (1·4–5·9)	n/s	44·1 (20·2–96·6)
International travel	1·5 (1·3–1·7)	0·1 (0·02–0·2)	n/s	n/s
Occur in autumn or winter	1·2 (1·0–1·3)	1·7 (1·3–2·1)	1·7 (1·1–2·5)	n/s
Live in an urban area	1·2 (1·0–1·5)	n/s	n/s	n/s

n/s, not statistically significant.

with Hispanic ethnicity is unexplained. It could reflect food preferences or be linked to cultural practices and should be further explored, but we do not think it is related to exposures abroad, because the travel-associated proportion is so low. Our finding that *C. upsaliensis* infections occur more often in autumn or winter months is intriguing but should be interpreted with caution given the small sample size.

We identified a small number of infections with other *Campylobacter* species. Patients with *C. fetus*

and *C. lari* infections were predominately male and tended to be older than those with *C. jejuni*. Older age and male predominance has been previously documented for *C. fetus* [5, 29] but is not well understood. It is possible that occupational exposure to cattle and sheep plays a role as many sporadic *C. fetus* cases reported in the literature have occurred among farmers or abattoir workers [5]. Patients with *C. fetus* infection were much more likely to have bloodstream infections and to be hospitalized than patients infected with any other species. Host factors, pathogen factors, or both may explain this characteristic. *C. lari* is associated with gastrointestinal infections and bacteremia especially in persons who are immunocompromised. It has been isolated from multiple environmental sources, including surface water, wild birds, and domestic animals [8], and contaminated water has been associated with infection [30].

Consistent with previous studies [31, 32], we found international travel to be a risk factor for antimicrobial-resistant infections, particularly among *C. coli* patients, and a high percentage of resistant infections occurred among travelers to Asia and South America. Resistance to ciprofloxacin is known to be common in these regions and appears to be increasing [33, 34]. Ciprofloxacin resistance among travelers is a concern because ciprofloxacin is a common treatment for diarrhea in returned travelers [35], although a macrolide is the drug of choice for *Campylobacter* infections [36]. We also found that a higher percentage of antimicrobial-resistant infections occurred in urban areas. This finding is consistent with reports from the Netherlands; they hypothesized consumption of ready-to-eat foods may be higher in urban areas [31]. It is also possible that persons in urban areas have more severe illness or co-morbidities. Interventions to combat resistance in the USA should focus on targeting domestic food sources, enhancing awareness among healthcare providers and travelers about the increased risk of resistant infections associated with international travel, and promoting appropriate antimicrobial stewardship.

Many factors affect the availability of *Campylobacter* species data in the USA and these should be taken into account when interpreting our findings. Although infection has been reportable in most states, it did not become a nationally notifiable infection until 2015 [37]. Only 22 (44%) states request or require positive specimens to be sent to SPHL for confirmation and speciation [38], and there are currently no national guidelines for the isolation and speciation of *Campylobacter*. Only 31% of 403 laboratories serving the FoodNet catchment area routinely speciate *Campylobacter* [39]. Thus, the process leading to the inclusion of cases in our dataset is complex, and the proportion of cases due to each species is not generalizable to all *Campylobacter* infection. Nonetheless, the differences we observe between species are unlikely to be due to selection bias, as these pre-speciation biases would be expected to affect all species similarly.

Many laboratories rely on isolation methods and selective media optimized for recovery of *C. jejuni* from the stool, decreasing the likelihood of recovering many other *Campylobacter* species. Selective media for isolation of specific non-*jejuni* species either has not been developed or is not widely available. Isolation methods, such as filtration, that would increase recovery of non-*jejuni* species are labor-intensive and few laboratories perform them. Traditional phenotypic identification methods [38] are widely performed and accurately identify hippurate-positive *C. jejuni*. However, these methods do not accurately identify hippurate-negative *Campylobacter* species or hippurate-negative *C. jejuni.* A method for species-level identification of *Campylobacter* using matrix-assisted laser desorption ionization-time of flight mass spectrometry (MALDI-TOF) has been described [40] and is becoming more widely used by clinical laboratories and SPHLs. DNA-based molecular methods can enhance species identification but can be expensive to implement. Since 2010, there has been an increase in the proportion of infections caused by species other than *C. jejuni.* This could reflect a real change in sources of human *Campylobacter* infections. Alternatively, it could be due to increased awareness of the non-*jejuni* species and improved ability to accurately identify these species in the state health departments after the implementation of CDC's quality assurance program for the identification of *Campylobacter* in 2008 and follow-up training made available to the SPHLs.

The use of culture-independent diagnostic tests (CIDTs) for identification of *Campylobacter* in FoodNet sites is increasing [41]. Decreasing availability of *Campylobacter* isolates has important implications for public health surveillance. While CIDTs are quicker and easier to perform, the most commonly used tests at present are limited in the *Campylobacter* species detected. They do not differentiate between *Campylobacter* species, nor do they yield an isolate for speciation or antimicrobial susceptibility testing. A strategy for obtaining species information, such as the reflex culture of specimens with a positive CIDT result, reflex culture if medically indicated for patient care, or collection of isolates from sentinel

laboratories, is needed to improve understanding of species-related differences and inform source attribution and risk factor studies. Advanced molecular detection methods, such as whole genome sequencing, will greatly facilitate identification and classification of strains and comparison of strains from human, food, animal, and environmental sources, but these methods rely on the availability of isolates to test. Coupled with standardized case exposure data, these approaches offer promise for a clearer understanding of the epidemiology of *Campylobacter* species in the USA, which in turn can inform prevention strategies.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Scallan E, *et al.*** Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases* 2011; **17**(1): 7–15.
2. **Centers for Disease Control and Prevention.** Antibiotic Resistance Threats in the United States, 2013 (http://www.cdc.gov/drugresistance/threat-report-2013/). Accessed 29 August 2014.
3. **Fitzgerald C.** Campylobacter. *Clinics in Laboratory Medicine* 2015; **35**(2): 289–298.
4. **FDA.** NARMS Integrated Report: 2012–2013. The National Antimicrobial Resistance Monitoring System: Enteric Bacteria (http://www.fda.gov/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/NationalAntimicrobialResistanceMonitoringSystem/ucm059103.htm). Accessed 19 November 2015.
5. **Wagenaar JA, *et al.*** *Campylobacter fetus* infections in humans: exposure and disease. *Clinical Infectious Diseases* 2014; **58**(11): 1579–1586. doi: 10.1093/cid/ciu085. Epub 2014 Feb 18.
6. **Gilbert MJ, *et al.*** Occurrence, diversity, and host association of intestinal *Campylobacter*, *Arcobacter*, and *Helicobacter* in reptiles. *PLoS ONE* 2014; **9**(7): e101599. doi: 10.1371/journal.pone.0101599. eCollection 2014.
7. **Acke E, *et al.*** Prevalence of thermophilic *Campylobacter* species in household cats and dogs in Ireland. *Veterinary Record* 2009; **164**(2): 44–47.
8. **Matsuda M, Moore JE.** The epidemiology and zoonotic transmission of thermophilic *Campylobacter lari*. *British Microbiology Research Journal* 2011; **1**(4): 104–121.
9. **Taylor EV, *et al.*** Common source outbreaks of *Campylobacter* infection in the USA, 1997–2008. *Epidemiology and Infection* 2013; **141**(5): 987–996. doi: 10.1017/S0950268812001744. Epub 2012 Aug 15.
10. **Gillespie IA, *et al.*** A case-case comparison of *Campylobacter coli* and *Campylobacter jejuni* infection: a tool for generating hypotheses. *Emerging Infectious Diseases* 2002; **8**: 937–942.
11. **Bessède E, *et al.*** Comparison of characteristics of patients infected by *Campylobacter jejuni*, *Campylobacter coli*, and *Campylobacter fetus*. *Journal of Clinical Microbiology*. 2014; **52**(1): 328–330. doi: 10.1128/JCM.03029-13. Epub 2013 Nov 6.
12. **Linton D, *et al.*** PCR detection, identification to species level, and fingerprinting of *Campylobacter jejuni* and *Campylobacter coli* direct from diarrheic samples. *Journal of Clinical Microbiology* 1997; **35**: 2568–2572.
13. **CDC.** *National Antimicrobial Resistance Monitoring System for Enteric Bacteria (NARMS): Human Isolates Final Report, 2013*. Atlanta, Georgia: U.S. Department of Health and Human Services, CDC, 2015.
14. **United States Department of Agriculture Economic Research Service** (http://www.ers.usda.gov/data-products/rural-urban-continuum-codes.aspx).
15. **Green CG, Krause DO, Wylie JL.** Spatial analysis of *Campylobacter* infection in the Canadian province of Manitoba. *International Journal of Health Geographics* 2006; **5**: 2.
16. **Ethelberg S, *et al.*** Spatial distribution and registry-based case-control analysis of *Campylobacter* infections in Denmark, 1991–2001. *American Journal of Epidemiology* 2005; **162**(10): 1008–1015. Epub 2005 Oct 5.
17. **Nylen G, *et al.*** The seasonal distribution of *Campylobacter* infection in nine European countries and New Zealand. *Epidemiology and Infection* 2002; **128**(3): 383–390.
18. **Doorduyn Y, *et al.*** Risk factors for indigenous *Campylobacter jejuni* and *Campylobacter coli* infections in The Netherlands: a case-control study. *Epidemiology and Infection* 2010; **138**(10): 1391–1404. doi: 10.1017/S095026881000052X. Epub 2010 Mar 12.
19. **Friedman CR, *et al.*** Risk factors for sporadic *Campylobacter* infection in the United States: a case-control study in FoodNet sites. *Clinical Infectious Diseases* 2004; **38**(Suppl. 3): S285-S296.
20. **Boysen L, Vigre H, Rosenquist H.** Seasonal influence on the prevalence of thermotolerant *Campylobacter* in retail broiler meat in Denmark. *Food Microbiology* 2011; **28**(5): 1028–1032. doi: 10.1016/j.fm.2011.02.010.
21. **Willis WL, Murray C.** *Campylobacter jejuni* seasonal recovery observations of retail market broilers. *Poultry Science* 1997; **76**(2): 314–317.
22. **Schonberg-Norio D, *et al.*** Swimming and *Campylobacter* infections. *Emerging Infectious Diseases* 2004; **10**: 1474–1477.
23. **Roux F, *et al.*** Elucidating the aetiology of human *Campylobacter coli* infections. *PLoS ONE* 2013; **8**(5): e64504. doi: 10.1371/journal.pone.0064504. Print 2013.
24. **Neal KR, *et al.*** Omeprazole as a risk factor for *Campylobacter* gastroenteritis: case-control study. *British Medical Journal* 1996; **312**: 414–415.

25. **Sopwith W, *et al.*** Investigation of food and environmental exposures relating to the epidemiology of *Campylobacter coli* in humans in Northwest England. *Applied and Environmental Microbiology* 2010; **76**(1): 129–135. doi: 10.1128/AEM.00942-09. Epub 2009 Oct 23.
26. **Zeigler M, *et al.*** Outbreak of campylobacteriosis associated with a long-distance obstacle adventure race – Nevada, October 2012. *MMWR Morbidity and Mortality Weekly Report* 2014; **63**(17): 375–378.
27. **Bessell PR, *et al.*** Using sequence data to identify alternative routes and risk of infection: a case-study of *Campylobacter* in Scotland. *BMC Infectious Diseases* 2012; **12**: 80. doi: 10.1186/1471-2334-12-80.
28. **Trokhymchuk A, *et al.*** Prevalence and diversity of *Campylobacter* species in Saskatchewan retail ground beef. *Journal of Food Protection* 2014; **77**(12): 2106–2110. doi: 10.4315/0362-028X.JFP-14-247.
29. **Gazaigne L, *et al.*** *Campylobacter fetus* bloodstream infection: risk factors and clinical features. *European Journal of Clinical Microbiology and Infectious Diseases* 2008; **27**(3): 185–189. Epub 2007 Nov 13.
30. **Broczyk A, *et al.*** Water-borne outbreak of *Campylobacter* laridis-associated gastroenteritis. *Lancet* 1987; **1**(8525): 164–165. PMID:2880002.
31. **Van Hees BC, *et al.*** Regional and seasonal differences in incidence and antibiotic resistance of *Campylobacter* from a nationwide surveillance study in The Netherlands: an overview of 2000–2004. *Clinical Microbiology and Infection* 2007; **13**(3): 305–310.
32. **Kassenborg HD, *et al.*** Fluoroquinolone-resistant *Campylobacter* infections: eating poultry outside of the home and foreign travel are risk factors. *Clinical Infectious Diseases* 2004; **38**(Suppl. 3): S279-S284.
33. **Pollett S, *et al.*** *Campylobacter* antimicrobial resistance in Peru: a ten-year observational study. *BMC Infectious Diseases* 2012; **12**: 193–200.
34. **Post A, *et al.*** Antibiotic susceptibility profiles among Campylobacter isolates obtained from international travelers between 2007 and 2014. *European Jounal of Clinical Microbiology and Infectious Diseases* 2017. doi: 10.1007/s10096-017-3032-6. [Epub ahead of print].
35. **Steffen R, Hill DR, DuPont HL.** Traveler's diarrhea: a clinical review. *Journal of the American Medical Association* 2015; **313**(1): 71–80. doi: 10.1001/jama.2014.17006. Review.
36. **Allos BM, Blaser M.** *Campylobacter jejuni* and related species. In: Mandell GL, Bennett JE, Dolin R, eds. *Mandell, Douglas, and Bennett's Principles and Practice of Infectious Diseases*, 7th edn. Churchill, Livingstone: Elsevier Press, Philadelphia, PA, 2010, p. 2799.
37. **Council of State and Territorial Epidemiologists.** *Standardized Surveillance for Campylobacteriosis and Addition to the Nationally Notifiable Condition List*. Atlanta, GA: Council of State and Territorial Epidemiologists, 2003 (http://c.ymcdn.com/sites/www.cste.org/resource/resmgr/2014PS/14_ID_09upd.pdf). Accessed 15 June 2015.
38. **CSTE.** State legal requirements for submission of isolates and other clinical materials by clinical laboratories: a review of state approaches (https://www.aphl.org/aboutAPHL/publications/Documents/StateRequirements_Appendix_v6.pdf) Accessed 15 May 2017.
39. **Hurd S, *et al.*** Clinical laboratory practices for the isolation and identification of *Campylobacter* in Foodborne Diseases Active Surveillance Network (FoodNet) sites: baseline information for understanding changes in surveillance data. *Clinical Infectious Diseases* 2012; **54** (Suppl. 5): S440-S445. doi: 10.1093/cid/cis245.
40. **Mandrell RE, *et al.*** Speciation of *Campylobacter coli*, *C. jejuni*, *C. helveticus*, *C. lari*, *C. sputorum*, and *C. upsaliensis* by matrix-assisted laser desorption ionization-time of flight mass spectrometry. *Applied and Environmental Microbiology* 2005; **71**(10): 6292–6307.
41. **Iwamoto M, *et al.*** Bacterial enteric infections detected by culture-independent diagnostic tests – FoodNet, United States, 2012–2014. *MMWR Morbidity and Mortality Weekly Report* 2015; **64**(9): 252–257.