Clinical Infectious Diseases

MAJOR ARTICLE

Increasing *Campylobacter* Infections, Outbreaks, and Antimicrobial Resistance in the United States, 2004–2012

Aimee L. Geissler,[a] Fausto Bustos Carrillo,[a] Krista Swanson, Mary E. Patrick, Kathleen E. Fullerton, Christy Bennett, Kelly Barrett, and Barbara E. Mahon

Centers for Disease Control and Prevention, Atlanta, Georgia

Background. Campylobacteriosis, a leading cause of foodborne illness in the United States, was not nationally notifiable until 2015. Data describing national patterns and trends are limited. We describe the epidemiology of *Campylobacter* infections in the United States during 2004–2012.

Methods. We summarized laboratory-confirmed campylobacteriosis data from the Nationally Notifiable Disease Surveillance System, National Outbreak Reporting System, National Antimicrobial Resistance Monitoring System, and Foodborne Diseases Active Surveillance Network.

Results. During 2004–2012, 303 520 culture-confirmed campylobacteriosis cases were reported. Average annual incidence rate (IR) was 11.4 cases/100 000 persons, with substantial variation by state (range, 3.1–47.6 cases/100 000 persons). IRs among patients aged 0–4 years were more than double overall IRs. IRs were highest among males in all age groups. IRs in western states and rural counties were higher (16.2/100 000 and 14.2/100 000, respectively) than southern states and metropolitan counties (6.8/100 000 and 11.0/100 000, respectively). Annual IRs increased 21% from 10.5/100 000 during 2004–2006 to 12.7/100 000 during 2010–2012, with the greatest increases among persons aged >60 years (40%) and in southern states (32%). The annual median number of *Campylobacter* outbreaks increased from 28 in 2004–2006 to 56 in 2010–2012; in total, 347 were reported. Antimicrobial susceptibility testing of isolates from 4793 domestic and 1070 travel-associated infections revealed that, comparing 2004–2009 to 2010–2012, ciprofloxacin resistance increased among domestic infections (12.8% vs 16.1%).

Conclusions. During 2004–2012, incidence of campylobacteriosis, outbreaks, and clinically significant antimicrobial resistance increased. Marked demographic and geographic differences exist. Our findings underscore the importance of national surveillance and understanding of risk factors to guide and target control measures.

Keywords. *Campylobacter*; *Campylobacter* infections; drug resistance; public health surveillance; disease outbreaks.

Campylobacteriosis, the most common bacterial diarrheal illness in the United States, annually causes an estimated 1.3 million illnesses, 13 240 hospitalizations, and 119 deaths with a cost of approximately $1.7 billion in medical care and lost productivity [1, 2]. *Campylobacter,* the causative agent of campylobacteriosis, usually results in self-limited, mild-to-severe gastroenteritis, but can lead to invasive infections. Persons with campylobacteriosis are at increased risk for postinfection long-term complications including reactive arthritis, irritable bowel syndrome, and Guillain-Barré syndrome (GBS) [3, 4]. Infection with the most commonly identified etiologic agent of GBS, *Campylobacter jejuni*, precedes paralysis in approximately 30% of patients [5]. Antimicrobial treatment is not required for mild, noninvasive infections; however, in severe or prolonged infections and during pregnancy, treatment can shorten illness duration and be life-saving [6, 7]. Erythromycin (a macrolide) is the preferred treatment, but ciprofloxacin (a fluoroquinolone) is often used empirically because of its broad spectrum of activity against enteric pathogens [6, 7]. Increasing resistance to both fluoroquinolone and macrolide agents has been reported in *Campylobacter* worldwide [6].

Campylobacter is transmitted by the fecal–oral route, usually through ingestion of contaminated food or water or through contact with animals or birds or environments contaminated by their feces [8–13]. Person-to-person transmission is uncommon and outbreaks are rare. *Campylobacter* data are reported regularly by sentinel sites to the Foodborne Diseases Active Surveillance Network (FoodNet) [14]. Although FoodNet data indicate that campylobacteriosis incidence is increasing, FoodNet represents only 15% of the population. Because campylobacteriosis incidence varies widely by site, we examined the national picture by using multiple data sources, providing a significant update to the previous national campylobacteriosis analysis conducted >30 years ago [14–16].

Received 1 February 2017; editorial decision 5 July 2017; accepted 17 July 2017; published online July 20, 2017.

[a]A. L. G. and F. B. C. contributed equally to this work.

Correspondence: A. Geissler, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, MS C-09, Atlanta, GA 30333 (ageissler@cdc.gov).

Clinical Infectious Diseases® 2017;65(10):1624–31

DOI: 10.1093/cid/cix624

METHODS

Data Collection

We analyzed the epidemiology of *Campylobacter*-associated infections, outbreaks, and antimicrobial resistance in the United States by summarizing data during 2004–2012 from 4 surveillance systems: the National Notifiable Diseases Surveillance System (NNDSS) [17]; the National Outbreak Reporting System (NORS) [11] and antecedent outbreak reporting systems; the National Antimicrobial Resistance Monitoring System (NARMS) [7]; and FoodNet [14].

NNDSS is a passive national surveillance system that collects demographic and geographic information on cases of nationally notifiable diseases and conditions [17]. Although campylobacteriosis did not become nationally notifiable until 2015, almost all states required reporting of cases to their health departments before 2015 and reported these cases to NNDSS [18]. We examined records of campylobacteriosis reported to NNDSS during 2004–2012 and verified data directly with individual states to improve data completeness and accuracy. We also requested and received data from 12 states and the District of Columbia for years they collected data but did not report to NNDSS. Our final data set, comprised of NNDSS data supplemented with data from states and FoodNet, which we refer to as the national data set, includes all 50 states and the District of Columbia.

NORS is a passive national surveillance system for investigated enteric disease outbreaks that collects data including etiology, vehicle, and number of illnesses and deaths. An outbreak is defined as ≥2 infections linked to a common source. Outbreaks of campylobacteriosis are investigated by health departments and reported through NORS, which integrates the Foodborne Disease Outbreak Surveillance System and the Waterborne Disease Outbreak Surveillance System [11].

NARMS is an isolate-based surveillance system that conducts antimicrobial susceptibility testing on enteric pathogens. For *Campylobacter*, NARMS conducts surveillance only in FoodNet sites, using a convenience sample of isolates for submission. FoodNet is a collaboration among the Centers for Disease Control and Prevention (CDC), 10 state health departments, the US Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS), and the US Food and Drug Administration (FDA). FoodNet conducts active, population-based surveillance for laboratory-confirmed infections of 9 bacterial and parasitic pathogens transmitted commonly through food and for hemolytic uremic syndrome [15]. Since 2004, the FoodNet catchment area has included all or part of 10 states [15]. Among other data, it captures whether patients traveled internationally before illness onset.

Geographic Distribution, Demographics, and Seasonality

Using the national data set, we calculated annual incidence rates (IRs) as the number of culture-confirmed campylobacteriosis cases per 100 000 population for the United States as a whole and for regions and states, both overall and by age group, sex, race, ethnicity, month, and rurality using US Census–defined regions and population estimates. We calculated IRs by month by dividing monthly case counts by 1/12th the yearly population. We used USDA Economic Research Service 2013 Rural-Urban Continuum Codes to categorize counties as metropolitan, nonmetropolitan, and rural [19].

Outbreaks

We reviewed NORS data during 2004–2012, including outbreak case numbers, route of transmission, and source [11].

Antimicrobial Susceptibility

We assessed antimicrobial susceptibility by using data obtained from NARMS and FoodNet. NARMS uses standardized methods to assess *Campylobacter* susceptibility to antimicrobial agents as previously described [6]. We limited our analysis to 2 clinically relevant antimicrobial agents, ciprofloxacin (resistance defined as a minimum inhibitory concentration [MIC] ≥1 µg/mL for both *C. jejuni* and *Campylobacter coli*) and erythromycin (resistance defined as MIC ≥8 µg/mL for C. jejuni and ≥16 µg/mL for *C. coli*). For this analysis, using FoodNet data, we classified cases in persons who reported travelling internationally ≤7 days before illness onset as travel-associated and all others as domestically acquired.

Statistical Analyses

We calculated IRs, incidence rate ratios (IRRs), 95% confidence intervals (CIs), and *P* values using SAS software version 9.3 (SAS Institute, Cary, North Carolina) and determined statistical significance ($P < .05$) using the 2-tailed Cochran-Mantel-Haenszel χ^2 test. We used ArcGIS 10 software (Esri, Redlands, California) to display IRs by state.

RESULTS

Incidence

During 2004–2012, a total of 303 520 cases of campylobacteriosis were reported by the 50 states and the District of Columbia, an average of 33 724 cases per year (range, 29 657–39 068). The IR was 11.4 cases per 100 000 persons (range, 10.2 in 2006 to 13.0 in 2012) (Table 1).

Geographic Distribution

Figure 1 indicates that IRs per 100 000 persons were highest in the West (16.2), followed by the Northeast (13.3) and Midwest (13.0), and were lowest in the South (6.8). For all regions, IRs were higher during 2010–2012 than in 2004–2006, with increases ranging from 10% (IRR, 1.10 [95% CI, 1.08–1.12]) in the Midwest to 32% (IRR, 1.32 [95% CI, 1.30–1.33]) in the South (Figure 2). By state, IRs per 100 000 persons ranged widely from 3.1 in Louisiana to 47.6 in Hawaii (Figure 1). IRs per 100 000 were highest in rural counties (14.2) and lowest in metropolitan counties (11.0) (Table 1). This pattern held for all age groups, sexes,

Table 1. Number of Cases, Incidence Rate, and Incidence Rate Ratio of Reported Culture-Confirmed *Campylobacter* Infection by Demographic Characteristic, Season, and Geographic Region—United States, 2004–2012

	2004–2012					
Characteristic	No. of Cases	(%)[a]	IR	(Range)	IRR	(95% CI)[b]
Age, y	299 933	(98.82)				
0–4	46 105	(15.37)	26.30	(23.39–28.41)	3.30	(3.25–3.35)
5–9	18 159	(6.05)	10.44	(8.95–12.00)	1.31	(1.29–1.34)
10–19	29 676	(9.89)	7.97	(6.78–9.16)	Ref.	NA
20–29	39 960	(13.32)	10.89	(9.59–12.33)	1.37	(1.35–1.39)
30–59	115 038	(38.35)	10.56	(9.80–11.78)	1.33	(1.31–1.34)
≥60	50 995	(17.00)	10.74	(8.67–13.66)	1.35	(1.33–1.37)
Sex	300 650	(99.05)				
Male	164 710	(54.78)	12.63	(11.23–14.18)	1.25	(1.24–1.26)
Female	135 940	(45.22)	10.08	(9.01–11.53)	Ref.	NA
Season[c]	303 520	(100)				
Summer	112 108	(36.94)	16.77	(14.32–18.52)	2.09	(2.07–2.11)
Fall	72 222	(23.79)	10.92	(9.55–12.54)	1.36	(1.34–1.38)
Winter	52 537	(17.31)	8.03	(7.15–8.93)	Ref.	NA
Spring	66 653	(21.96)	9.97	(8.30–11.97)	1.24	(1.23–1.26)
Region[d]	303 520	(100)				
West	102 470	(33.76)	16.18	(14.05–18.87)	2.38	(2.36–2.40)
Midwest	69 244	(22.81)	12.96	(12.02–14.67)	1.91	(1.89–1.93)
Northeast	63 388	(20.88)	13.27	(11.59–15.62)	1.95	(1.93–1.98)
South	68 418	(22.54)	6.79	(5.67–8.39)	Ref.	NA
Rurality[e]	301 561	(99.35)				
Metropolitan	247 500	(82.07)	11.02	(9.91–12.67)	Ref.	NA
Nonmetropolitan	37 749	(12.52)	12.97	(11.34–14.97)	1.18	(1.16–1.19)
Rural	16 312	(5.41)	14.20	(12.19–16.10)	1.29	(1.27–1.31)
Total	303 520	(100)	11.44	(10.20–12.97)	NA	NA

Abbreviations: CI, confidence interval; IR, incidence rate; IRR, incidence rate ratio; NA, not applicable; ref, reference comparison group.

[a]Percentages for total in each category were calculated using total number of cases (303 520); percentages for subcategories were calculated using the number of cases for the subcategory total.

[b]All $P < .001$.

[c]Season: winter = December, January, February; spring = March, April, May; summer = June, July, August; fall = September, October, November.

[d]Region: Midwest = Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, Wisconsin; Northeast = Connecticut, Maine, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont; South = Alabama, Arkansas, Delaware, District of Columbia, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, Virginia, West Virginia; West = Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, Wyoming.

[e]Geography defined using 2013 Rural-Urban Continuum Codes, Economic Research Service.

seasons, and regions. For all counties, IRs were 21% higher (95% CI, 20%–22%) during 2010–2012 than in 2004–2006 (Figure 2).

Demographics

IRs per 100 000 persons were highest overall among children aged 0–4 years (26.3) and in all but 3 states (Alaska, Connecticut, and Maine) where incidence was highest among persons aged ≥60 years (Table 1). Among all states, IRs were lowest among persons aged 10–19 years (8.0) (Table 1). All age group-specific IRs increased from 2004–2006 to 2010–2012, with the largest increases occurring among persons aged ≥60 years (42% [95% CI, 39%–45%]) (Figure 2).

IRs were higher among males than females overall (IRR, 1.25 [95% CI, 1.24–1.26]) and across all age groups, races/ethnicities, seasons, and geographic regions (Table 1; data not shown).

Race was provided in only 62% of reports and ethnicity in 52%. Therefore, we do not report absolute IRs, but compare IRRs for racial/ethnic groups across age groups because, assuming that race and ethnicity are not differentially reported by age group, those comparisons remain robust despite missing data. The majority of infections reported occurred among whites (52.4%); however, Figure 3 demonstrates that, compared with whites, incidence was lower among blacks in all age groups but higher for American Indians or Alaska Natives in the majority of age groups. Comparing Asians/Pacific Islanders with whites, incidence was higher among persons aged <10 years, but lower among other age groups. IRRs were 1.4- to 2.7-fold higher among age groups <20 and ≥60 years for Hispanics, compared with non-Hispanics (Figure 3).

Seasonality

IRs per 100 000 persons were highest during June–August (16.8) and lowest during December–February (8.0), with an overall ratio of 1.4 spring/summer to fall/winter cases (Table 1). This pattern was observed for all regions and age groups. A small but distinct

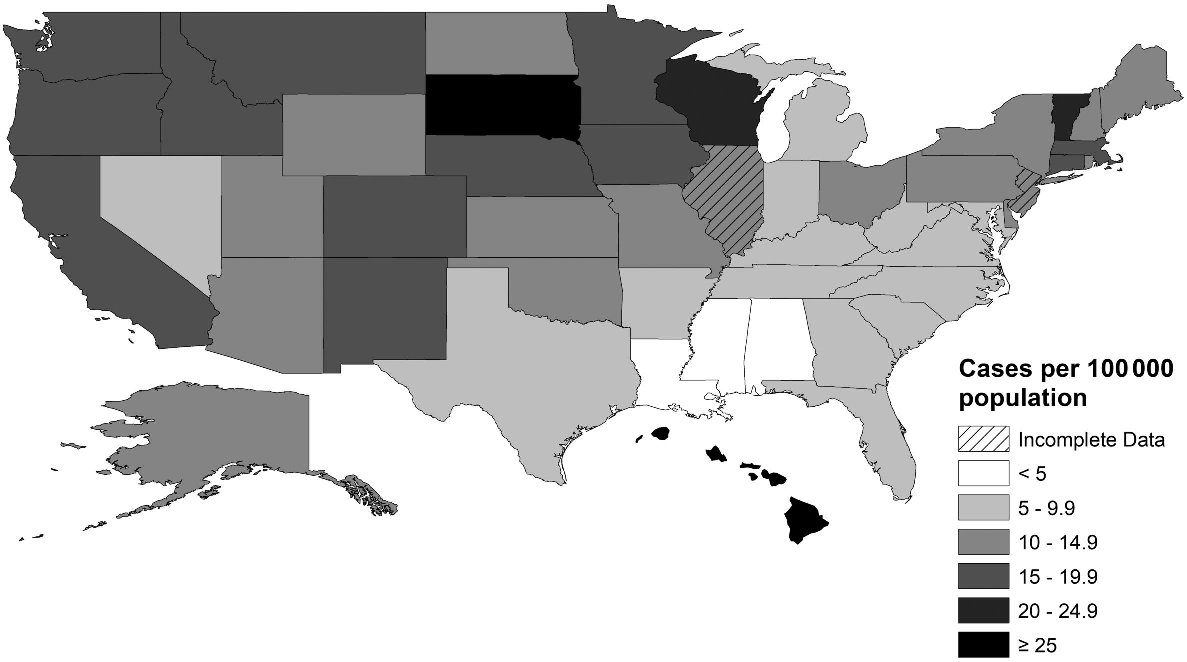

Figure 1. Incidence rate of reported culture-confirmed *Campylobacter* infection by state—United States, 2004–2012 (N = 303 520).

January peak was evident for persons aged <30 years. For all seasons, IRs were higher during 2010–2012 than in 2004–2006, with increases ranging from 18% (95% CI, 15%–20%) in the winter to 27% (95% CI, 25%–30%) in the spring. Comparing rural counties with nonmetropolitan and metropolitan counties, IRs were significantly higher in rural and nonmetropolitan counties during summer (IRR, 1.33 [95% CI, 1.32–1.36]), fall (IRR, 1.21 [95% CI, 1.19–1.23]), and spring (IRR, 1.13 [95% CI, 1.11–1.16]), but were similar during winter (IRR, 1.03 [95% CI, 1.01–1.06]). The January peak was observed only in metropolitan counties.

Outbreaks

During 2004–2012, a total of 347 campylobacteriosis outbreaks were reported, with 8650 illnesses and no deaths. The median

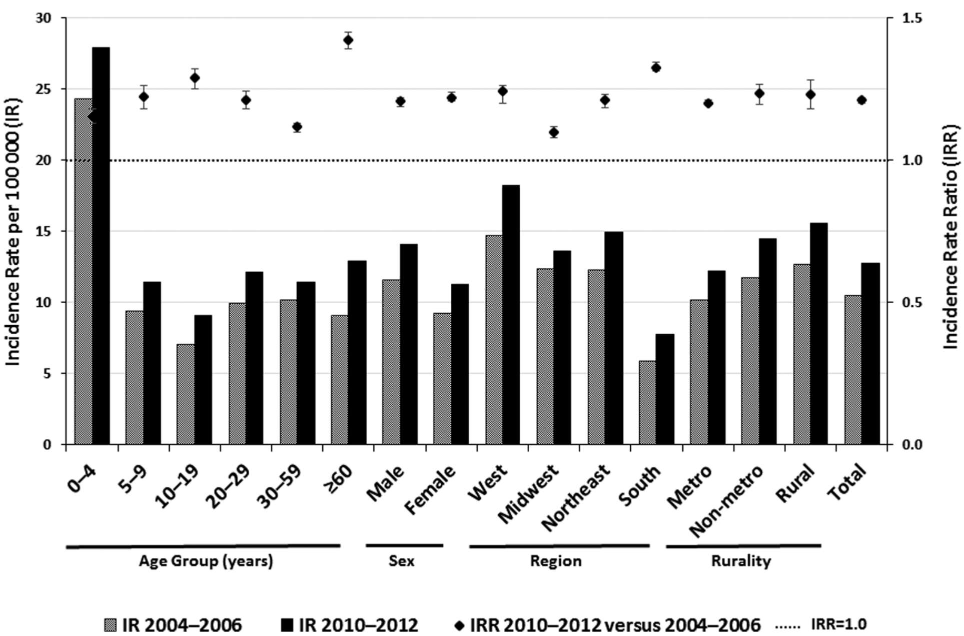

Figure 2. Incidence rates (IRs) and incidence rate ratios (IRRs) of reported culture-confirmed *Campylobacter* infection by time period—United States, 2004–2012 (N = 303 520). All IRRs were statistically significant ($P \leq .05$); 95% confidence intervals for IRRs are depicted with error bars.

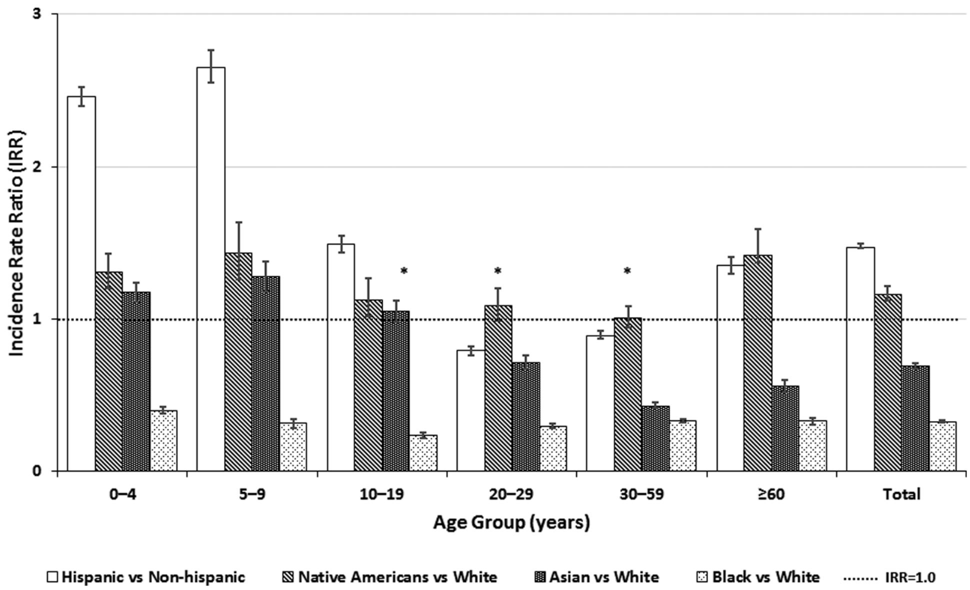

Figure 3. Incidence rate ratios (IRRs) of reported culture-confirmed *Campylobacter* infection among ethnic and racial groups by age group—United States, 2004–2012 (N = 303 520). Not statistically significant ($P \geq .05$); 95% confidence intervals for IRRs are depicted with error bars.

annual number of outbreaks was 31 (mean, 38 [range, 20 in 2004 to 68 in 2012]), with a median of 6 illnesses per outbreak (mean, 25 [range, 2–1644]). The ratio of 4.3 for spring/summer vs fall/winter outbreaks is >3 times greater than the ratio for cases overall. During 2004–2006, the median annual number of outbreaks was 28, with a median of 8 illnesses per outbreak (mean, 54). During 2010–2012, the annual median was 56 outbreaks, but the illnesses/outbreak median decreased to 5 (mean, 14).

The transmission route was reported for 290 of 347 (84%) outbreaks. The majority, 242 of 290 (70%), were foodborne, resulting in 5183 illnesses with a median of 7 illnesses per outbreak (mean, 21). Implicated food vehicles were reported for 125 (52%) of these foodborne outbreaks, with dairy products implicated in 86 (69%). Less commonly implicated foods included poultry (19 outbreaks [15%]), produce (9 outbreaks [7%]), other meats (6 outbreaks [5%]), and shellfish (5 outbreaks [4%]). Contaminated water was implicated in only 7% (25/347) of outbreaks; however, with a median of 26 illnesses/outbreak (mean, 126), these resulted in 59% (3034/5183) of outbreak-associated illnesses. Among the 25 water-associated outbreaks, 21 (76%) were associated with contaminated drinking water and 4 (24%) with recreational water exposure. Less common transmission routes included animal contact (16 outbreaks [5%]), resulting in 132 illnesses, and person-to-person transmission (7 outbreaks [2%]), resulting in 37 illnesses.

Antimicrobial Resistance

A total of 8219 *Campylobacter* isolates were tested for antimicrobial susceptibility. Resistance to ciprofloxacin and erythromycin was observed in 1926 (23.4%) and 173 (2.1%) isolates, respectively. Travel history was reported for 5863 (71%) cases, of which 1070 (18%) were associated with international travel. The majority of resistant infections were domestically acquired (760/1477), although resistance proportions were higher among travel-associated (62.4% ciprofloxacin; 4.6% erythromycin) than among domestically acquired infections (14.4% ciprofloxacin; 1.5% erythromycin). Comparing data from 2004–2010 with the more recent years 2011–2012, resistance to ciprofloxacin increased among domestic (13.0% vs 17.0%) infections, and resistance to ciprofloxacin and erythromycin was more commonly travel-associated (60.2 vs 67.5% and 3.6% vs 6.8%, respectively) (Table 2).

DISCUSSION

Our analysis reveals broad increases in the incidence of *Campylobacter* infection across demographic groups and throughout the United States during 2004–2012. Campylobacteriosis incidence was highest in the West and lowest in the South but increased substantially during the study period across all regions. We also found consistently higher rates in rural counties than in metropolitan counties, but incidence increased across all types of counties. Our findings are consistent with the incidence increases and demographic patterns that FoodNet has described [1, 15, 16]. The overall annual IR of 11.4 per 100 000 is 16% lower than the rate reported from FoodNet, likely reflecting underreporting in NNDSS, which is a passive system [15]. It could also reflect true differences. Studies examining whether geographic differences in medical diagnostic practices or in levels of poultry contamination are associated with the observed variability in campylobacteriosis have not

Table 2. Ciprofloxacin and Erythromycin Resistance Among *Campylobacter* Isolates by Time Period—National Antimicrobial Resistance Surveillance System, United States, 2004–2012[a]

	2004–2012		2004–2010		2011–2012		2004–2010 vs 2011–2012
Resistance	No.	(%)	No.	(%)	No.	(%)	*P* Value[b]
Travel associated	1070	(18.3)	747	(19.1)	323	(16.4)	NA
Ciprofloxacin resistant	668	(62.4)	450	(60.2)	218	(67.5)	.02
Erythromycin resistant	49	(4.6)	27	(3.6)	22	(6.8)	.02
Domestically acquired	4793	(81.7)	3154	(80.9)	1639	(83.5)	NA
Ciprofloxacin resistant	689	(14.4)	411	(13.0)	278	(17.0)	<.01
Erythromycin resistant	71	(1.5)	44	(1.4)	27	(1.6)	.49
Total	5863	(100)	3901	(100)	1962	(100)	NA
Ciprofloxacin resistant	1357	(23.1)	861	(22.1)	496	(25.3)	<.01
Erythromycin resistant	120	(2.0)	71	(1.8)	49	(2.5)	.08

Abbreviation: NA, not applicable.

[a]N = 5863 (71%) isolates from patients who had information on travel history during 7 days prior to illness onset.

[b]Statistical significance defined as $P \leq .05$.

produced clear answers [20–23]. Little information is available regarding the overall contribution of waterborne sources, especially untreated drinking water, to *Campylobacter* infections. Our data do not explain these geographic differences, but they do highlight the regions and demographic groups at greatest risk. *Campylobacter* has long been among the most common causes of bacterial diarrheal illness in the United States, so broad recent increases in incidence emphasize the need for effective control measures.

The demographic patterns we report both confirm and extend previous observations. Consistent with other studies, the highest incidence occurred among children aged <5 years and among males [16, 21, 24, 25]. However, in 3 states persons aged >60 years had the highest incidence of infection, which may reflect differences in geographical differences in exposures and risks of infection. Compared with non-Hispanics and whites, markedly higher rates occurred among Hispanics and American Indian or Alaska Native populations, respectively, across almost all age groups. Conversely, rates among blacks were lower. Some degree of protective immunity can be produced by exposure to *Campylobacter* [6], so the age-related patterns we observe may reflect age-related exposures producing such immunity. Collection of standardized case exposure data could facilitate investigation of risk factors and transmission pathways [15]. The sex and race/ethnicity patterns for campylobacteriosis differ from those of other enteric infections, for example FoodNet data, indicate that *Salmonella* rates are higher in females than males, and highest in blacks compared with other races [15].

Our seasonality data reveal noteworthy patterns beyond the known summer seasonality of *Campylobacter* [26]. First, geographic areas and age groups with higher incidence had more pronounced summer peaks than those with lower incidence. Second, we observed a small but distinct January peak among age groups <30 years and in metropolitan counties. Third, over the study period we observed the highest seasonal increase in the spring. Finally, the spring/summer peak was substantially greater for outbreaks than for cases overall. These observations may be associated with seasonality of exposures to *Campylobacter*, although how precisely this might occur is as yet undetermined.

Campylobacter outbreaks also increased 2-fold during the study period. This pattern contrasts with other enteric pathogens such as *Salmonella*, where the number of outbreaks was similar in 2004–2006 to 2010–2012 [27]. The majority of *Campylobacter* outbreaks are foodborne, with unpasteurized milk and poultry the most common vehicles. Studies in the United States and elsewhere have reported that poultry is an important outbreak vehicle and risk factor for sporadic infections and that chicken livers specifically may be an increasingly important vehicle [9, 10, 21, 28–30]. The dramatic increase in *Campylobacter* outbreaks associated with unpasteurized milk has been noted previously [31, 32]. This increase coincides with an increase in consumer demand for unpasteurized milk, which has led to changes in policies to reduce restrictions on the sale of unpasteurized milk in some states [31]. Waterborne outbreaks, although less common than foodborne outbreaks, tend to be larger, and have recently been associated with both contaminated drinking water and obstacle races [33–35].

Changes in antimicrobial resistance can fluctuate quickly; when comparing the 2 most recent years with 2004–2010, we found concerning trends in *Campylobacter* resistance to both ciprofloxacin and erythromycin. For ciprofloxacin, although the resistant proportion was highest for travel-associated infections, we found not only that most resistant infections were domestically acquired but also that the resistant proportion among domestically acquired infections increased over the study period. Although resistance was less common for erythromycin, both travel-related and domestically acquired resistant infections were reported, and the resistant proportion increased for travel-related infections. Ciprofloxacin-resistant campylobacteriosis increased rapidly after the approval of fluoroquinolones for use in poultry and has been shown to be associated with poultry consumption, findings that contributed to the withdrawal of the approval for poultry by the FDA [36]. Our findings echo global concerns about antimicrobial resistance across pathogens and agents and emphasize the need for effective stewardship of antimicrobial agents wherever they are used [37].

This study had limitations beyond those previously discussed. It is estimated that 30 *Campylobacter* illnesses occur for every culture-confirmed and reported illness, and our analysis included only culture-confirmed cases [1]. In FoodNet, the percentage of campylobacteriosis cases diagnosed by culture-independent diagnostic tests (CIDTs) has increased from 8% in 2010 to 28% in 2015 [38, 39]. The increasing availability and rapid adoption of CIDTs is further decreasing the proportion of cases captured in current surveillance systems [38, 39]. Another limitation is that data regarding species of *Campylobacter* causing infections are collected by few states and are not reported to NNDSS. Lack of species data is unlikely to affect our results substantially because a large majority of infections are caused by *C. jejuni.* Nonetheless, seasonality, demographics, and risk factors for campylobacteriosis vary by species; therefore, we are unable to assess the extent to which our results are driven by differences in species causing infections among different areas or population subgroups [26, 40].

Our study highlights an urgent need for improved prevention and control of *Campylobacter* infection and outbreaks in the United States. Major food safety measures recently implemented hold promise. In 2011 the Food Safety Modernization Act granted FDA authority to regulate food facilities, establish standards for safe produce, recall contaminated foods, and oversee imported foods [41]. In 2016 USDA implemented the first pathogen reduction performance standards for chicken parts (former standards were for whole birds), microbial testing at a point closer to the final product at poultry facilities, and posting of individual companies' food safety performance online [42]. Monitoring the impact of these measures with surveillance data will be important to determine if additional measures are needed.

Campylobacter infection is common worldwide, and multiple countries have taken innovative steps to control it. These interventions have recently involved pairing surveillance with advanced molecular techniques, for example, multilocus sequence typing (MLST) and whole-genome sequencing. A notable example is New Zealand, where a common MLST subtype was linked to a specific poultry producer. Voluntary and regulatory interventions focused on poultry were implemented and were followed by a 54% decline in national campylobacteriosis incidence [43]. Whole-genome sequencing offers promise for the future; linking WGS data with exposure history data might facilitate rapid identification of exposures associated with outbreaks and sporadic cases.

CONCLUSIONS

Campylobacter is the most common cause of bacterial enteric infection in the United States, yet little national information has been available. These data provide baseline rates for monitoring change now that campylobacteriosis is a nationally notifiable disease and reveal several newly described aspects of *Campylobacter* epidemiology in the United States. The marked geographic variability seen in our analysis suggests that FoodNet sentinel surveillance, which is conducted in only 10 states, may not accurately reflect important aspects of *Campylobacter* epidemiology. Nonetheless, the age, race, and ethnicity-specific patterns we describe are also seen in FoodNet data alone. FoodNet sites collect standardized demographic, species, and exposure data for most reported *Campylobacter* cases. These data could be used as a comparison group to explore sources of infection among the groups identified in this study with the highest incidence or increasing incidence of infection. In addition, increasing antimicrobial resistance among both domestic and travel-associated infections reinforces the need for responsible antibiotic use in both humans and animals. Uptake of CIDTs threatens the utility of our surveillance systems, and strategies to incorporate advanced molecular diagnostics in routine surveillance are needed to maintain and improve surveillance for antimicrobial resistance, outbreaks, and the role of various *Campylobacter* species in human illness. Our findings also underscore the importance of standardizing national surveillance for campylobacteriosis, which is important in understanding the burden of infection, better describing geographic variations and differences among species, elucidating risk factors, and targeting prevention and control measures.

Notes

Acknowledgments. We thank Mike Hoekstra for his technical assistance in data analysis. We express our gratitude for the countless efforts and contributions of the Centers for Disease Control and Prevention (CDC), state health department, and CDC staff who collected, transmitted, and verified the data included in this analysis.

Disclaimer. The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the CDC.

Potential conflicts of interest. All authors: No reported conflicts of interest. All authors have submitted the ICMJE Form for Disclosure of Potential Conflicts of Interest. Conflicts that the editors consider relevant to the content of the manuscript have been disclosed.

References

1. Scallan E, Hoekstra RM, Angulo FJ, et al. Foodborne illness acquired in the United States—major pathogens. Emerg Infect Dis **2011**; 17:7–15.
2. Buzby JC, Allos BM, Roberts T. The economic burden of *Campylobacter*-associated Guillain-Barré syndrome. J Infect Dis **1997**; 176(suppl 2):S192–7.
3. Pope JE, Krizova A, Garg AX, Thiessen-Philbrook H, Ouimet JM. *Campylobacter* reactive arthritis: a systematic review. Semin Arthritis Rheum **2007**; 37:48–55.
4. Marshall JK. Post-infectious irritable bowel syndrome following water contamination. Kidney Int **2009**; 112:S42–43.
5. Yuki N, Hartung HP. Guillain-Barré syndrome. N Engl J Med **2012**; 366:2294–304.

6. Blaser MJ. Clinical aspects of *Campylobacter jejuni* and *Campylobacter coli* infections. In: Nachamkin I, Szymanski CM, Blaser MJ, eds. *Campylobacter*. Vol 3. Washington DC: ASM Press, **2008**; 99–121.
7. Gupta A, Nelson JM, Barrett TJ, et al; NARMS Working Group. Antimicrobial resistance among *Campylobacter* strains, United States, 1997-2001. Emerg Infect Dis **2004**; 10:1102–9.
8. Friedman CR, Hoekstra RM, Samuel M, et al; Emerging Infections Program FoodNet Working Group. Risk factors for sporadic *Campylobacter* infection in the United States: a case-control study in FoodNet sites. Clin Infect Dis **2004**; 38(suppl 3):S285–96.
9. Fullerton KE, Ingram LA, Jones TF, et al. Sporadic *Campylobacter* infection in infants: a population-based surveillance case-control study. Pediatr Infect Dis J **2007**; 26:19–24.
10. Taylor EV, Herman KM, Ailes EC, et al. Common source outbreaks of *Campylobacter* infection in the USA, 1997-2008. Epidemiol Infect **2013**; 141:987–96.
11. Centers for Disease Control and Prevention. Surveillance for foodborne disease outbreaks—United States, 2009–2010. MMWR Morb Mortal Wkly Rep **2013**; 62:41–2.
12. Greig JD, Ravel A. Analysis of foodborne outbreak data reported internationally for source attribution. Int J Food Microbiol **2009**; 130:77–87.
13. Painter JA, Hoekstra RM, Ayers T, et al. Attribution of foodborne illnesses, hospitalizations, and deaths to food commodities by using outbreak data, United States, 1998-2008. Emerg Infect Dis **2013**; 19:407–15.
14. Centers for Disease Control and Prevention. Foodborne Diseases Active Surveillance Network (FoodNet): FoodNet surveillance final report for 2014. Atlanta, GA: CDC, **2013**.
15. Centers for Disease Control and Prevention. Incidence and trends of infection with pathogens transmitted commonly through food—Foodborne Diseases Active Surveillance Network, 10 U.S. sites, 2006–2013. MMWR Morb Mortal Wkly Rep **2014**; 63:328–32.
16. Tauxe RV, Pegues DA, Hargrett-Bean N. *Campylobacter* infections: the emerging national pattern. Am J Public Health **1987**; 77:1219–21.
17. Centers for Disease Control and Prevention. National Notifiable Diseases Surveillance System (NNDSS) data collection and reporting. Available at: http://wwwn.cdc.gov/nndss/script/DataCollection.aspx. Accessed 29 November 2016.
18. Council for State and Territorial Epidemiologists. Creation of a national campylobacteriosis case definition. Available at: http://c.ymcdn.com/sites/www.cste.org/resource/resmgr/2014ps/14_id_09upd.pdf. Accessed 10 August 2016.
19. US Department of Agriculture Economic Research Service. Rural-urban continuum codes. **2013**. Available at: http://www.ers.usda.gov/data-products/rural-urban-continuum-codes/documentation.aspx. Accessed 4 June 2016.
20. Effler P, Ieong MC, Kimura A, et al. Sporadic *Campylobacter jejuni* infections in Hawaii: associations with prior antibiotic use and commercially prepared chicken. J Infect Dis **2001**; 183:1152–5.
21. Ailes E, Demma L, Hurd S, et al. Continued decline in the incidence of *Campylobacter* infections, FoodNet 1996-2006. Foodborne Pathog Dis **2008**; 5:329–37.
22. Ailes E, Scallan E, Berkelman RL, Kleinbaum DG, Tauxe RV, Moe CL. Do differences in risk factors, medical care seeking, or medical practices explain the geographic variation in campylobacteriosis in Foodborne Diseases Active Surveillance Network (FoodNet) sites? Clin Infect Dis **2012**; 54(suppl 5):S464–71.
23. Patrick M, Kadam P, Ghoneim R, et al. Enumeration of *Campylobacter* on chickens at processing and retail: an explanation of regional difference in incidence of *Campylobacter* observed in FoodNet sites? In: International Association for Food Protection Annual Meeting. Des Moines, Iowa, August 1–3, **2011**.
24. Nelson W, Harris B. Campylobacteriosis rates show age-related static bimodal and seasonality trends. N Z Med J **2011**; 124:33–9.
25. Samuel MC, Vugia DJ, Shallow S, et al. Epidemiology of sporadic *Campylobacter* infection in the United States and declining trend in incidence, FoodNet 1996–1999. Clin Infect Dis **2004**; 38(suppl 3):S165–74.
26. McCarthy ND, Gillespie IA, Lawson AJ, et al. Molecular epidemiology of human *Campylobacter jejuni* shows association between seasonal and international patterns of disease. Epidemiol Infect **2012**; 140:2247–55.
27. Centers for Disease Control and Prevention. National outbreak surveillance summaries 2004–2012. Available at: http://www.cdc.gov/nors/publications.html. Accessed 29 November 2016.
28. Centers for Disease Control and Prevention. Multistate outbreak of *Campylobacter jejuni* infections associated with undercooked chicken livers—northeastern United States, 2012. MMWR Morb Mortal Wkly Rep **2013**; 62:874–6.
29. Scott MK, Geissler A, Poissant T, et al; Centers for Disease Control and Prevention (CDC). Notes from the field: campylobacteriosis outbreak associated with consuming undercooked chicken liver pâté—Ohio and Oregon, December 2013–January 2014. MMWR Morb Mortal Wkly Rep **2015**; 64:399.
30. Little CL, Gormley FJ, Rawal N, Richardson JF. A recipe for disaster: outbreaks of campylobacteriosis associated with poultry liver pâté in England and Wales. Epidemiol Infect **2010**; 138:1691–4.
31. Mungai EA, Barton CB, Gould LH, Increased outbreaks associated with nonpasteurized milk, United States, 2007–2012. Emerg Infect Dis **2015**; 21:119–22.
32. Longenberger AH, Palumbo AJ, Chu AK, Moll ME, Weltman A, Ostroff SM. *Campylobacter jejuni* infections associated with unpasteurized milk—multiple States, 2012. Clin Infect Dis **2013**; 57:263–6.
33. Jackson BR, Zegarra JA, López-Gatell H, et al; GBS Outbreak Investigation Team. Binational outbreak of Guillain-Barré syndrome associated with *Campylobacter jejuni* infection, Mexico and USA, 2011. Epidemiol Infect **2014**; 142:1089–99.
34. Stuart TL, Sandhu J, Stirling R, et al. Campylobacteriosis outbreak associated with ingestion of mud during a mountain bike race. Epidemiol Infect **2010**; 138:1695–703.
35. Zeigler M, Claar C, Rice D, et al; Centers for Disease Control and Prevention (CDC). Outbreak of campylobacteriosis associated with a long-distance obstacle adventure race—Nevada, October 2012. MMWR Morb Mortal Wkly Rep **2014**; 63:375–8.
36. Nelson JM, Chiller TM, Powers JH, Angulo FJ. Fluoroquinolone-resistant *Campylobacter* species and the withdrawal of fluoroquinolones from use in poultry: a public health success story. Clin Infect Dis **2007**; 44:977–80.
37. World Health Organization. Antimicrobial resistance: global report on surveillance 2014. World Health Reports 2014:1–257. Available at: http://www.who.int/drugresistance/documents/surveillancereport/en/. Accessed 29 November 2016.
38. Iwamoto M, Huang JY, Cronquist AB, et al; Centers for Disease Control and Prevention. Bacterial enteric infections detected by culture-independent diagnostic tests—FoodNet, United States, 2012-2014. MMWR Morb Mortal Wkly Rep **2015**; 64:252–7.
39. Huang JY, Henao OL, Griffin PM, et al. Infection with pathogens transmitted commonly through food and the effect of increasing use of culture-independent diagnostic tests on surveillance—Foodborne Diseases Active Surveillance Network, 10 U.S. sites, 2012-2015. MMWR Morb Mortal Wkly Rep **2016**; 65:368–71.
40. Gillespie IA, O'Brien SJ, Frost JA, et al; *Campylobacter* Sentinel Surveillance Scheme Collaborators. A case-case comparison of *Campylobacter coli* and *Campylobacter jejuni* infection: a tool for generating hypotheses. Emerg Infect Dis **2002**; 8:937–42.
41. US Food and Drug Administration. FDA Food Safety Modernization Act (FSMA), January 4, 2011. Available at: http://www.fda.gov/Food/GuidanceRegulation/FSMA/. Accessed 29 November 2016.
42. US Department of Agriculture. USDA finalizes new food safety measures to reduce *Salmonella* and *Campylobacter* in poultry. USDA News Release No. 0032.16. Available at: https://www.usda.gov/media/press-releases/2016/02/04/usda-finalizes-new-food-safety-measures-reduce-salmonella-and. Accessed 20 July 2017.
43. Sears A, Baker MG, Wilson N, et al. Marked campylobacteriosis decline after interventions aimed at poultry, New Zealand. Emerg Infect Dis **2011**; 17:1007–15.