

Review article
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Epidemiologic characteristics of *Campylobacter* infections in high-income countries: a systematic review

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Abstract

Introduction. The *Campylobacter* is the most common bacterial cause of foodborne illnesses in high-income countries. In contrast to other infectious diseases, the number of *Campylobacter* cases has increased in developed countries over the last ten years. A systematic review has been conducted to identify the factors contributing to incidence of *Campylobacter* infection in developed countries and to estimate it by age, sex, geography, and season.

Materials and methods. The review was limited to studies published in English from 2010–2021; eight nationwide surveillance and register-based cohort studies, which met the selection criteria, were included in the review.

Results. While the highest incidence of *Campylobacter* infection was reported among young children living in rural areas, the highest number of *Campylobacter* cases among adults was recorded in urban settings. Nevertheless, population-wise, children and older adults are most affected, while the incidence rates are higher in males than in females, with cases peaking every summer.

Conclusion. *Campylobacter* infection is a public health concern in high-income countries, being difficult to eradicate and having become an urgent challenge to the existing well-developed surveillance systems. Additionally, the threat of antibiotic resistance in *Campylobacter* is growing at an alarming rate. The reasons behind *Campylobacter* affecting more men than women as well as the age and geographic distribution of the infection still need thorough research.

Keywords: *Campylobacter* species, *Campylobacter* outbreaks, Analytical studies, Epidemiologic trends, National surveillance

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Научный обзор
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Эпидемиологическая характеристика инфекций *Campylobacter* в странах с высоким уровнем дохода: систематический обзор

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Аннотация

Введение. *Campylobacter* — наиболее частая бактериальная причина болезней пищевого происхождения в странах с высоким уровнем доходов. В отличие от других инфекционных заболеваний, количество случаев *Campylobacter* увеличилось в развитых странах за последние 10 лет. Систематический обзор был проведён для выявления факторов, способствующих распространению инфекции *Campylobacter* в развитых странах, и оценки её по возрасту, полу, географии и сезону.

Материалы и методы. Обзор ограничен исследованиями, опубликованными на английском языке за 2010–2021 гг. В обзор были включены восемь общенациональных эпиднадзора и когортных исследований на основе регистров, которые соответствовали критериям отбора.

Результаты. В то время как самая высокая заболеваемость *Campylobacter* была зарегистрирована среди детей раннего возраста, живущих в сельской местности, самое большое количество случаев *Campylobacter* среди взрослых было зарегистрировано в городских условиях. Тем не менее больше всего страдают дети и пожилые люди, а уровень заболеваемости выше у мужчин, чем у женщин, причём пик заболеваемости приходится на каждое лето.

Заключение. Инфекция *Campylobacter* представляет собой проблему для общественного здравоохранения в странах с высоким уровнем доходов, её трудно искоренить, и она стала неотложной проблемой для существующих хорошо развитых систем эпиднадзора. Кроме того, угроза устойчивости *Campylobacter* к антибиотикам растёт с угрожающей скоростью. Причины, по которым *Campylobacter* поражает больше мужчин, чем женщин, а также возраст и географическое распространение инфекции ещё требуют тщательного исследования.

Ключевые слова: виды *Campylobacter*, вспышки *Campylobacter*, аналитические исследования, эпидемиологические тенденции, национальный надзор

Источник финансирования. Авторы заявляют об отсутствии внешнего финансирования при проведении исследования.

Конфликт интересов. Авторы декларируют отсутствие явных и потенциальных конфликтов интересов, связанных с публикацией настоящей статьи.

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Introduction

Campylobacter bacteria are bacterial enteric pathogens responsible for diarrheal illnesses such as gastroenteritis. It has been estimated that *Campylobacter* species cause around 96 million foodborne infections worldwide every year [1]. *Campylobacter* typically are comma or s-shaped gram-negative bacteria. The genus *Campylobacter* consists of 32 species and 9 subspecies; however, two species, *C. jejuni* and *C. coli* are most common pathogens in humans and the leading cause of *Campylobacter* outbreaks [2]. *Campylobacter* infection is classified both as zoonotic and foodborne. It has a zoonotic nature because is carried by animals, being especially common for chickens [3] and is foodborne because can be transmitted to humans through undercooked and cross-contaminated foods of animal origin. Furthermore, contaminated water, unpasteurized milk, and rare, though possible human-to-human transmission are also a common source of foodborne *Campylobacter* infection [4].

Campylobacter infection is usually self-limiting, causing mild to severe symptoms like diarrhea, abdominal cramps, fever, body aches, nausea, vomiting, and fatigue. However, *Campylobacter* infection can be invasive and fatal when pathogens enter the bloodstream, causing bacteraemia. *Campylobacter* infection can be severe among elderly, immunosuppressed, HIV-positive, alcohol-dependent individuals, or in patients who had gastrointestinal surgery [5]. Post-infection complications may include Guillain–Barré syndrome, Miller–Fisher syndrome [6], inflammatory bowel disease, colorectal cancer [7], and reactive arthritis [8].

Campylobacter infection poses a global threat to human health. It remains a persistent problem in developed countries. For example, in the United States, *Campylobacter* infections annually cause an estimated 1.3 million illnesses, around 13,240 hospitalizations,

and 119 deaths with a cost of \$1.7 billion in medical care [9]. Furthermore, in other high-income countries such as the United Kingdom and members of the European Union, in 2016, the EU member states collectively reported 246,307 infection cases [10], and 52,381 infection cases were reported in England and Wales [11]. In the same year, 243,49 confirmed cases of *Campylobacter* infection were reported in Australia. Hence, it is evident that infections caused by *Campylobacter* species place a substantial burden on the public health system in high-income countries.

Therefore, this study aims to assess epidemiologic characteristics of *Campylobacter* infection in high-income countries by analysing the national surveillance data and published studies. The objectives of this study are as follow:

- To explore the relationship between *Campylobacter* infection and age.
- To explore the relationship between *Campylobacter* infection and gender.
- To explore the relationship between *Campylobacter* infection and geographical factors.
- To explore the relationship between *Campylobacter* infection and seasonal factors.

Materials and methods

Protocol

This systematic review is conducted according to the PRISMA guidelines.

Search Strategy

The PubMed and Google Scholar search engines were used to find the articles with the following keywords and keyword combinations: *Campylobacter*, *Campylobacter* species, foodborne illness outbreaks, epidemiologic trends, epidemiologic characteristics,

analytical studies, national surveillance. The search span covered the period from 2010 through 2021, because the epidemiology of the pathogens is rapidly changing. The latest and updated data are instrumental for providing valid information about the current situation. A total of 1,628 and 25,100 articles were retrieved from PubMed and Google Scholar, respectively.

Inclusion Criteria

- Studies must be in English.
- Studies must be either analytical or based on national surveillance data.
- Studies must focus on outbreaks caused by *Campylobacter* infection.
- Studies must have multi-component settings and outcomes.
- Studies must be performed in high-income countries.
- Clinical data used in the studies must be limited to humans.

Exclusion Criteria

- Studies that are not in English.
- Studies that are not analytical or not based on national surveillance data.
- Studies that do not focus on high-income countries.

Data Extraction

The data extraction process was performed in four steps using the PRISMA guidelines (**Fig. 1**).

The four steps were as follows:

1. Identification: this step involved searching for scientific publications with PubMed and Google

Scholar. A total of 6,728 articles were retrieved, covering the period from 2010 through 2021. After the duplicates had been removed, only 5,168 articles remained.

2. Screening: the title and abstract screening resulted in removal of another 4,732 articles, leaving a selection of 436 articles. 11 articles were added from other sources (directly from journals such as «Eurosurveillance»), resulting in a total number of 447 articles provisionally selected for the review.
3. Eligibility: lacking full texts, another 57 articles were winnowed out; the remaining 383 articles were matched against the inclusion and exclusion criteria.
4. Final selection: in the final step, eight articles met the criteria and were selected for research synthesis and review.

In the latter, data on author names, publication dates, location, subject numbers, age range, gender, surveillance and intervention period, demographic distribution, geographical distribution, seasonal distribution were extracted.

No meta-analysis was performed, as the studies lacked methodological consistency, including target population, measurement variables, and statistical methods.

Quality Assessment

The quality of the studies was assessed against four categories of biases:

- 1) selection bias;
- 2) detection bias;

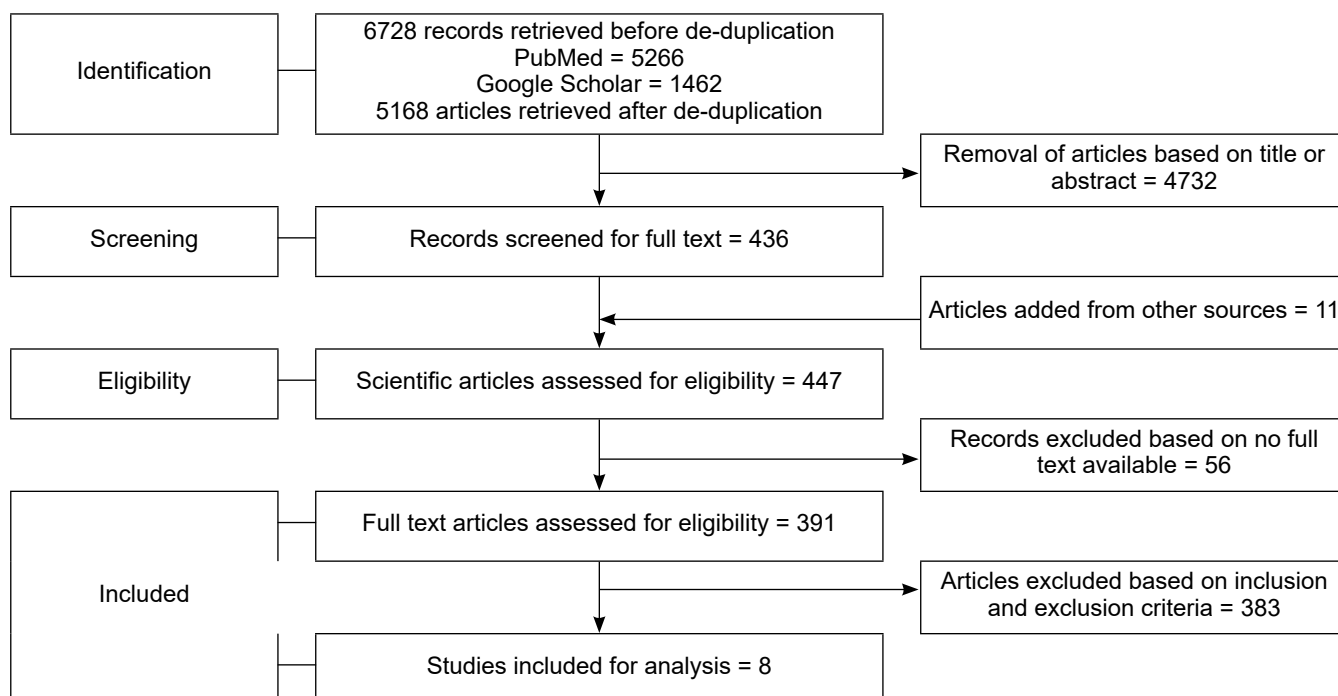


Fig. 1. Flow Diagram — Study Selection.

- 3) attribution bias;
- 4) reporting bias.

The studies were assessed using a 7 point-rating scale. The points were given to the studies according to the requirements of quality assessment. **Table 1** shows the complete list of categories and scores.

Results

Characteristics of studies

The fundamental characteristics of the studies are presented in **Table 2**. Out of 8 selected studies, 1 was conducted in England and Wales [12], 1 in Germany [13], 1 in Australia [14], 1 in Israel [15], 1 in the United States [16], 1 in Denmark [17], 1 in New Zealand [18], and 1 in Ireland [19]. In all the studies, the gender referred to males and females. However, age groups varied from study to study. In England and Wales, the age range was 0–100 years [12], in Germany, the age range was 0–70+ years [13], in Australia, the age range was 0–80 years [14], in Israel, the age range was 0–65+ years [15], in the United States, the age range was 0–60+ years [16], in Denmark, the age range was 0–90 years [17], in New Zealand, the age range was 0–15 years [18], and in Ireland, the age range was 0–65+ years [19].

All the cases analysed in the studies were laboratory confirmed. The researchers from England and

Table 1. Study quality assessment criteria

Quality assessment criteria		
Category	Sub-category	Score points
Selection bias	Methods of the study	0 = Unclear 1 = Partially clear 2 = Appropriately clear
Detection bias	Outcome assessment	0 = Unclear 1 = Partially clear 2 = Appropriately clear
Attribution bias	Outcome data	0 = Unclear 1 = Partially clear 2 = Appropriately clear
Reporting bias	Selective reporting	0 = Outcome measure reported without explanation 1 = Outcome measure reported with explanation

Wales [12], USA [16], New Zealand [18], and Ireland [19] used national data sets to collect the data on *Campylobacter* cases for interventions, while researchers from Germany [13], Australia [14], Israel [15], and Denmark [17] collected the data from national centres for disease control. The data ranged widely by their epidemiologic focus. However, collectively, the studies covered the age, gender, geographic location, and season. Some studies also presented data on ethnicity, hospitalizations, travel-related infections, deprivation index, and clinical details.

Table 2. Summary of the main characteristics of included studies and their respective quality assessment scores

Study	Location	Period	Age	Sex	Case validation	Source of information	Case distribution	Study quality
G.L. Nichols <i>et al.</i> , 2012 [12]	England and Wales	1989–2009	0–100 years	Male, female	Laboratory confirmed	National Diagnostic Laboratories (Oracle database)	Ethnic origin, postcode, deprivation index, population density	7
A. Schielke <i>et al.</i> , 2014 [13]	Germany	2001–2010	0–70+ years	Male, female	Laboratory confirmed	Robert Koch Institute (Federal Public Health Institute)	Age, sex, residence, hospitalisation, district of exposure, detected <i>Campylobacter</i> species	7
C.R. Moffat <i>et al.</i> , 2016 [14]	Australia	1998–2013	0–80 years	Male, female	Laboratory confirmed	Communicable Disease Network of Australia	Gender, age, season, states and territory	5
R. Bassal <i>et al.</i> , 2016 [15]	Israel	1999–2012	0–65+	Male, female	Laboratory confirmed	Israel Center of Disease Control	Age, gender, population group	6
A.L. Geissler <i>et al.</i> , 2017 [16]	USA	2004–2012	0–60+	Male, female	Laboratory confirmed	National Notifiable Disease Surveillance, National Outbreak Reporting System, National Antimicrobial Resistance Monitoring System, FoodNet	Age, race, ethnicity, sex, months, residence	7
K.G. Kuhn <i>et al.</i> , 2017 [17]	Denmark	2000–2015	0–90	Male, female	Laboratory confirmed	Danish National Institute of Infections Disease Control	Birth, sex, address, municipality, region of residence	7
E. Jeffs <i>et al.</i> , 2018 [18]	New Zealand	1997–2016	0–15	Male, female	Laboratory confirmed	National Minimum Dataset and the ESR Notifiable Disease Database	Age, sex, ethnicity, hospitalisation, report date, onset date, case status, clinical details	6
L. O'Connor <i>et al.</i> , 2020 [19]	Ireland	2004–2016	0–65+	Male, female	Laboratory confirmed	Computerised Infection Disease Reporting	Age, sex, geographical area, season	7

Epidemiologic characteristics of *Campylobacter*

The gender, age and geographic distribution of *Campylobacter* incidence, the relationship between the case rates and seasons, and the epidemiologic demography of cases from different countries are presented in **Table 3**.

Reported cases by country. From 1989 through 2009, a total number of 99,471 cases of *Campylobacter* infection were reported in England and Wales. In Germany, a total number of 588,308 cases of *Campylobacter* infection were recorded during 2001–2010. From 1998 through 2013, a total number of 245,023 *Campylobacter* infection cases were reported in Australia. In Israel, 40,978 *Campylobacter* infection cases were documented from 1999 through 2012. During 2004–2012, 303,520 campylobacteriosis cases were reported in the United States. In Denmark, 60,725 cases of *Campylobacter* infection were recorded from 2000 through 2015. From 1997 through 2016, New Zealand reported 39,970 cases of *Campylobacter* infection. In Ireland, there were 27,034 cases of *Campylobacter* infection reported from 2004 through 2016.

***Campylobacter* classification.** Four studies [12, 13, 15, 16] mentioned the type of *Campylobacter* that had caused outbreaks in the countries, while such data were not available in the other 4 studies [14, 17–19]. In

England and Wales, Israel, and the United States, the *Campylobacter* species that caused the outbreaks were identified as *C. jejuni* and *C. coli*. In Germany, the outbreaks were caused by *C. jejuni*, *C. coli*, *C. lari*, *C. fetus*, and *C. upsaliensis*.

Gender distribution. All the studies show that males have higher incidence rates of *Campylobacter* infection than females. However, the incidence rates varied widely across countries, time periods, and studies. In England and Wales, during 1989–2009, there were 14% more reported cases of infection in males than in females with an incidence rate ratio of 1.14. In Germany, from 2001 through 2010, the mean incidence was higher in men (96/100,000 population) than in women (83/100,000 population) with an incidence rate ratio of 1.15. In contrast to other age groups, among the 20–29-year-olds, women demonstrated higher incidence (113/100,000 population) compared to men (101/100,000). In Australia, from 1998 through 2013, the incidence was 20% higher among men than among women, with an incidence rate ratio of 1.20. For the 1999–2012 period, no Israeli data on incidence rate ratios were found; however, there were data that men accounted for 56.1% of all infection cases, while women comprised 43.9%.

In the United States, during 2004–2012, men and women accounted for 54.78% and 45.22% of all re-

Table 3. Summary of epidemiologic demography, *Campylobacter* species, campylobacter infections distribution in age, gender with geography and season

Study	Location	Period	Number of reported cases	<i>Campylobacter</i> type	Gender distribution	Age distribution	Geographical distribution	Seasonal distribution
G.L. Nichols <i>et al.</i> , 2012 [12]	England and Wales	1989–2009	99,471	<i>C. jejuni</i> , <i>C. coli</i>	Higher incidence rate in men	Higher incidence rate in age group (50+ years)	Higher incidence rate in rural area	May–June
A. Schielke <i>et al.</i> , 2014 [13]	Germany	2001–2010	588,308	<i>C. jejuni</i> , <i>C. coli</i> , <i>C. lari/fetus</i> / <i>upsaliensis</i>	Higher incidence rate in men, except age group 20–29	Higher incidence rate in age group (0–4 years)	Higher incidence rate in urban area	May–July
C.R. Moffat <i>et al.</i> , 2016 [14]	Australia	1998–2013	245,023	No information provided	Higher incidence rate in men	Ibid	Incidence rate varied state to state	September–February
R. Bassal <i>et al.</i> , 2016 [15]	Israel	1999–2012	40,978	<i>C. jejuni</i> , <i>C. coli</i>	Ibid	Ibid	No information provided	April–August
A.L. Geissler <i>et al.</i> , 2017 [16]	USA	2004–2012	303,520	<i>C. jejuni</i> , <i>C. coli</i>	Ibid	Ibid	Higher incidence rate in rural and non-metropolitan areas	June–August
K.G. Kuhn <i>et al.</i> , 2017 [17]	Denmark	2000–2015	60,725	No information provided	Ibid	Higher incidence rate in age groups (0–4; 20–24; 25–29 years)	Higher incidence rate in urban and intermediate areas	May–October
E. Jeffs <i>et al.</i> , 2018 [18]	New Zealand	1997–2016	39,970	No information provided	Ibid	Higher incidence rate in age group (0–4 years)	Incidence rate varied region to region	December–January
L. O'Connor <i>et al.</i> , 2020 [19]	Ireland	2004–2016	27,034	No information provided	Ibid	Ibid	Higher incidence rate in rural areas	April–May

ported cases of *Campylobacter* infection, respectively, with an incidence rate ratio of 1.25. In Denmark, during 2000–2015, the incidence among men was 73.2 cases per 100,000 population, while the incidence among women was 64.5 cases per 100,000 population, with an incidence rate ratio of 1.14. In Ireland, from 2004 through 2012, 53.4% and 46.7% of all *Campylobacter* cases were recorded in men and in women, respectively, with an incidence rate ratio of 1.15. Only in New Zealand, during 1997–2016, gender differences in the incidence were insignificant, with 51% and 49% of all *Campylobacter* cases reported in men and women, respectively.

Age distribution. In England and Wales, from 1989 through 2009, higher numbers of *Campylobacter* cases were reported among young adults (under 40 years) living in London. However, starting from 2000, the downward trend was observed in the number of *Campylobacter* cases in the 0–4-year-old age group. Nevertheless, all factors considered, the age-specific incidence rates were highest among senior citizens. In Germany, from 2001 through 2010, the *Campylobacter* incidence was highest among children from 0 to 4 years old compared to all other age groups (123/100,000 and 69/100,000, respectively). Interestingly, a high incidence was also recorded in the 20–29-year-old age group (107/100,000) compared to all other age groups (69/100,000).

In Australia, from 1998 through 2013, the highest age-specific incidence rates of *Campylobacter* infection were observed in the 1–4-year-old age group, both in males and females (254.5/100,000 and 204.2/100,000, respectively). Overall, the lowest incidence was reported among females aged 10–19 years. In Israel, from 1999 through 2012, the increase in *Campylobacter* incidence was observed in all age ranges. Nevertheless, the 0–4-year-old age group was reported as most affected (394.6/100,000) compared to other age groups.

In the United States, from 2004 through 2012, the highest incidence rates of *Campylobacter* infection were recorded among children aged 0–4 years (26.3/100,000). In the meantime, three states (Alaska, Connecticut, and Maine) reported the highest incidence rates among people aged ≥ 60 years. Overall, in all the states, the lowest incidence rates of *Campylobacter* infection were observed among the 10–19-year-old age group. However, the incidence rates increased among all age groups from 2004–2006 through 2010–2012, senior citizens aged ≥ 60 years being most affected.

In Denmark, from 2000 through 2015, significantly higher *Campylobacter* incidence was reported in 3 age groups: 20–24-year-olds (136/100,000), 25–29-year-olds (114/100,000), and 0–4-year-olds (96.8/100,000). In New Zealand, from 1997 through 2016, the most affected age group was that of 0–4-year-olds. From 1997 through 2007, the *Campylobacter* incidence among 0–4-year-old age group was 417 cases per 100,000

population, while 248 cases per 100,000 population were recorded in the same age group between 2008 and 2016. In Ireland, from 2004 through 2016, the highest *Campylobacter* incidence was reported in the 0–4-year-old age group (152/100,000).

Geographical distribution. From 1898 through 2009, in England and Wales, the study used postcodes to identify the geographic distribution of campylobacter cases. Cases of *Campylobacter* per 100,000 population were higher in areas of low population density (rural) compared to areas of high population density (urban). Note that less postcode reporting in areas of high population density could introduce some bias; however, the subset analysis of areas with over 90% postcode reporting showed higher incidence in rural settings.

From 2001 through 2012, in Germany, the incidence in rural settings was 69/100,000 population and in urban areas — 73/100,000 population. Children living in rural regions were more frequently affected by *Campylobacter* infection than children living in urban areas, which is especially obvious in the age group of <10 years (130/100,000 and 83/100,000). On the contrary, the incidence among 20–69-year-olds living in urban settings was higher than among their peers living in rural settings (77/100,000 and 64/100,000, respectively). In addition, the incidence of *Campylobacter* infection was higher in the eastern German federal states than in the western German federal states.

In Australia, from 1998 through 2013, the geographical distribution was analysed state-by-state rather than by urban/rural area of residence. Over the observed period, the *Campylobacter* incidence rates varied from state to state. The highest incidence (177.5/100,000 and 172.2/100,000) was reported in South Australia in 2001 and 2012; the lowest incidence (69.2/100,000 and 66.7/100,000) was reported in Victoria in 1998 and 2011.

In the United States, the *Campylobacter* incidence was higher in rural areas (14.2/100,000) compared to urban areas (11/100,000). In addition, the study also reported the following geographical areas: the West, the Northwest, the Midwest, and the South. In the West, the *Campylobacter* incidence rates were highest (16.2/100,000), while in the Northwest, the incidence rates were lower (13.3/100,000) as compared to the rates reported in the West. However, the lowest incidence rates were reported in the South (6.8/100,000) and in the Midwest (13/100,000).

The study from Israel did not provide any data on geographical distribution. In Denmark, during 2000–2015, the country was divided into four zones designated as urban, intermediate, distant, and rural. Overall, the highest *Campylobacter* incidence was recorded in intermediate areas (106.4/100,000) and urban settings (61.2/100,000). Furthermore, the *Campylobacter* incidence in the 0–4-year-old age group was higher in distant areas (142/100,000) and in rural areas

(225.6/100,000). On the contrary, the *Campylobacter* incidence in the age group 50+ years was higher in intermediate areas (106.4/100,000) and urban areas (149.5/100,000).

From 1997 through 2016, in New Zealand, the study mentioned the relationship between the *Campylobacter* incidence and geographical locations, though it did not provide any explanatory information about the distribution. Yet, the study mentioned that the highest incidence was recorded in South Canterbury with an incidence rate ratio of 1.77. In Ireland, during 2004–2016, no data on incidence in rural or urban areas were available; however, the highest *Campylobacter* incidence (58.7/100,000 population) was reported in the Midlands (a rural area).

Seasonal Distribution. In England and Wales, from 1989 through 2009, the *Campylobacter* incidence tended to peak in summer. The increased rate of infection between week 18 (early May) and week 22 (early June) is consistently reported every year. In Germany, from 2001 through 2010, the *Campylobacter* incidence increased from May to July and peaked in August. However, a small peak in the monthly incidence was also recorded in January.

During 1998–2013, in Australia, the *Campylobacter* incidence demonstrated similar rates in winter and autumn, while the highest incidence was recorded in spring and summer, with incidence rate ratios of 1.18, and 1.17, respectively. In Israel, from 1999 through 2012, the incidence was reported to peak from April through August.

In the United States, from 2004 through 2012, the highest *Campylobacter* incidence rates were reported during June–August and the lowest rates were observed during December–January. Interestingly, a small peak in the incidence was observed in January in the age group <30 years. In Denmark, the highest *Campylobacter* incidence rates were recorded during May–October, with a peak in August during 2000–2015.

In New Zealand, from 1997 through 2016, the highest *Campylobacter* incidence rates were recorded during summer months from December through February. In Ireland, a sharp increase in the *Campylobacter* incidence was observed in summer, during April–May, reaching a peak in August. The univariate analysis showed the incidence rate ratio of 1.57 in spring and incidence rate ratios of 1.45 and 1.09 in summer and autumn, respectively.

Discussion

The systematic review presents the analysis of 8 studies. It has been found that epidemiologic characteristics of *Campylobacter* infections vary from country to country and depend on various factors such as age, gender, season/weather, and geographical areas.

It has been found that *Campylobacter* incidence was higher among men compared to women in all eight

studies, except for the German 20–29-year-old age group where the incidence was higher among women than men. Although higher *Campylobacter* incidence rates among men still lack explanation, it can be assumed that there are factors that may contribute to increased susceptibility to *Campylobacter* infections among men compared to women. Among them, there are such factors as culture, sex hormones, behaviour, genetics, and gut microbiome [20–22]. Regarding possible cultural factors, in all the eight countries in this study, there is no evidence that the gender of a child has any influence on seeking for medical care for acute infections. Similarly, there is no evidence that adult men in these eight countries are more likely than women to seek medical care for acute infections, though there is some evidence that men tend to use health services less than women do [23]. One of the behaviour-related factors mentioned is that men are more likely to get *Campylobacter* infection as they tend to spend more time outdoors as compared to women [19]. However, sex hormones, genetics, and gut microbiome may also play a role in gender distribution of incidence, urging for further research.

In all 8 studies, the 0–4-year-old age group was most affected by the *Campylobacter* infection. High *Campylobacter* incidence rates reported among the 0–4-year-olds are not surprising and can be caused by multiple factors, including poor hygiene practices, higher chances of being clinically tested, having close contacts with pets or animals, and not having a strong immune system. However, these high incidence rates of *Campylobacter* infection among young children are in line with the epidemiology of other gastrointestinal infections showing a comparable age-specific pattern [13, 17]. In addition, in Denmark, 20–24 and 25–29-year-old age groups were also among the age groups most affected by *Campylobacter* infections. It may be associated with the fact that young adults leave home to pursue education or to work, and they may not follow basic food hygiene practices when learning how to cook for themselves [24].

Furthermore, in case of urban vs rural areas, higher incidence rates of *Campylobacter* infection were observed in rural areas. What causes such urban/rural difference in *Campylobacter* incidence rates remains unclear. The contributing factors may include proximity to ruminants and other farm animals or differences in access to healthcare [12]. On the contrary, in Denmark, higher numbers of *Campylobacter* cases were recorded in urban areas than in rural settings, and the reasons are still unclear.

Seasonal outbreaks of *Campylobacter* infection were mostly reported in spring and summer in all the countries. *Campylobacter* infection outbreaks in spring and summer can be explained by existence of favourable conditions for pathogens, which tend to thrive due to environmental and climate factors; *Campylobacter*

pathogens become more prevalent in poultry during warm seasons, causing an increase in *Campylobacter* incidence that reaches its peak in summer [25]. Other reasons that may be responsible for seasonal outbreaks include people's eating habits and hygiene practices. In addition, a small peak of *Campylobacter* incidence was reported in winter both in the United States and Germany. However, further research is needed to explain the relationship between this peak and the winter season.

Additionally, only three studies [12, 13, 17] discussed the relationship between travel and *Campylobacter* incidence, suggesting that surveillance systems need to concentrate on imported infection cases and their contribution to the local incidence. Imported cases should be given more focused attention, considering increasing antibiotic resistance of *Campylobacter* pathogens [26].

Conclusion

Undoubtedly, outbreaks of *Campylobacter* infection remain a serious public health concern in high-income countries. Different *Campylobacter* species affect age groups, genders, and locations (urban/rural) in different seasons of the year. Although there is treatment available for *Campylobacter* infection, the growing antibiotic and antimicrobial resistance of *Campylobacter* poses a serious threat. Based on the literature synthesis, it can be concluded that while *Campylobacter* infections are found in every age, gender, locality, their case rates are highest among very young or very old age groups, mostly men, living in rural areas, with incidence peaks in summer. While further research is required to understand the above patterns of *Campylobacter* incidence, there is also a need for promoting health education in prevention of such outbreaks in general population.

Strengths of the Study

The study thoroughly assessed the literature describing *Campylobacter* infection cases in different high-income countries during different periods. Epidemiologic characteristics of *Campylobacter* infection in humans are presented in relation to age, gender, area of residence, and season.

Limitations of the Study

The study was unable to synthesise the data on *Campylobacter* infection cases in terms of ethnicity, travel, mortality and morbidity, as only very few studies addressed such categories. Therefore, these aspects remained uncovered.

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