Characteristics of *Campylobacter* Gastroenteritis Outbreaks in Australia, 2001 to 2016

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Abstract

Campylobacter spp. are a globally important cause of bacterial gastroenteritis, with Australia experiencing higher rates of illness than many comparable high-income countries. Despite the high disease incidence, outbreaks of campylobacteriosis in Australia are infrequently detected and reported. We examined the epidemiology of *Campylobacter* outbreaks in Australia, with particular emphasis on assessing transmission routes and evidence as reported during public health investigations. A national register of enteric and foodborne disease outbreaks was used to summarize data on all *Campylobacter* outbreaks reported in Australia between 2001 and 2016. Outbreak data were reviewed and analyzed for trends over time. Additional information was sought from state and territory epidemiologists, to validate transmission routes. A total of 84 *Campylobacter* outbreaks were reported, with 51 (61%) being classified as foodborne. Specific food vehicles were identified for 33 (65%) outbreaks, with 28 (85%) implicating chicken or chicken-containing dishes. Although no increase in the proportion of foodborne *Campylobacter* outbreaks was observed, examination of specific food vehicles demonstrated a significant increase in outbreaks because of poultry-liver containing foods ($p=0.04$). One quarter of all 1042 outbreak-associated cases occurred in aged-care facilities (ACFs), including 17 associated hospitalizations and three deaths. After review of evidence data, 23 outbreaks (27%) were determined to have an unknown route of transmission, including 10 (43%) outbreaks occurring in ACFs. *Campylobacter* spp. remain a less commonly reported cause of gastroenteritis outbreaks in Australia. Although many reported outbreaks can be linked to foodborne transmission, over a quarter were unable to identify either a food vehicle or transmission source, particularly for outbreaks occurring in aged care. Increased efforts to improve evidence collection and understanding of transmission dynamics for outbreaks of campylobacteriosis, particularly in aged care, are required.

Keywords: *Campylobacter*, disease outbreaks, foodborne diseases, waterborne diseases, zoonoses, homes for the aged

Introduction

CAMPYLOBACTER SPP. ARE an important cause of gastroenteritis and responsible for an annual global estimate of 96 million (95% UI 52–177 million) cases of foodborne infection (Kirk *et al.*, 2015). Although campylobacteriosis most commonly presents as a self-limiting enterocolitis, extraintestinal infections (e.g., bacteremia) and postinfectious complications

such as Guillain–Barre syndrome, reactive arthritis, and irritable bowel syndrome may also occur (Fitzgerald, 2015).

Poultry, particularly broilers, are recognized as the primary reservoir for foodborne infections, with ruminants such as cattle and sheep and monogastric species such as pigs also being important carriers (Kaakoush *et al.*, 2015). In addition to illness acquired through undercooked or cross-contaminated foods of animal origin, campylobacteriosis

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may also result from animal interactions, ingestion of unpasteurized milk, contaminated water, or less commonly through person-to-person contact (Kaakoush *et al.*, 2015).

In high-income settings like the European Union (EU) and England, where foodborne disease surveillance is well established, *Campylobacter* spp. are the most commonly reported enteric pathogens (European Food Safety Authority [EFSA], 2017; Nichols *et al.*, 2012). During 2016, 246,307 cases were reported among EU member states (notification rate 66.3 per 100,000 population) and 52,381 cases were reported in England and Wales (notification rate 89.7 per 100,000) (European Food Safety Authority [EFSA], 2017; Gastrointestinal Infections Department, 2018). Similarly in Australia, disease incidence remains high (Moffatt *et al.*, 2017a), with 24,239 confirmed cases reported in 2016, a national notification rate of 100.2 per 100,000 (Australian Government Department of Health, 2019).

Despite the high incidence and case numbers, *Campylobacter* outbreaks remain less frequently reported in Australia (Unicomb *et al.*, 2009; Moffatt *et al.*, 2017a). This contrasts markedly with *Salmonella enterica*, another enteric pathogen of public health significance, responsible for ~1000 outbreaks in Australia between 2001 and 2016 (Ford *et al.*, 2018). Nevertheless, outbreak data contribute to our understanding of *Campylobacter*'s epidemiology, showing food vehicles such as poultry-liver pâté have become an established cause of outbreaks internationally (Little *et al.*, 2010; Lanier *et al.*, 2018).

Using national outbreak and disease notifications data, we examined *Campylobacter* outbreaks in Australia, expanding

upon a previous assessment for the period 2001–2006 (Unicomb *et al.*, 2009). The aim of this study was to provide a contemporary understanding of the epidemiology of campylobacteriosis outbreaks in Australia, with particular focus on transmission routes and evidence levels obtained during investigations.

Materials and Methods

All Australian states and territories have public health legislation mandating the reporting of *Campylobacter* infections and suspected outbreaks of food or waterborne gastroenteritis (OzFoodNet Working Group, 2018). However, campylobacteriosis only became notifiable in the state of New South Wales (NSW) in 2017, falling outside of study parameters. OzFoodNet, a national network performing surveillance and investigation of enteric and foodborne disease in Australia, maintains a National Outbreak Register (hereafter called the Register) with all states and territories contributing outbreak data (Kirk *et al.*, 2008). Two states, NSW and Victoria, use local alternatives to the Register for recording details of nonfoodborne *Campylobacter* outbreaks.

Data were extracted from the Register providing details of *Campylobacter* outbreaks between 2001 and 2016. Information included nominated transmission routes, settings where outbreaks occurred, settings where food was prepared (if applicable), dates of outbreak notifications, implicated *Campylobacter* species (if known), numbers of persons exposed, numbers of cases, hospitalizations and deaths, types of epidemiological investigation (case-control study, analytical

TABLE 1. DEFINITIONS FOR OUTBREAKS OF CAMPYLOBACTERIOSIS BY TRANSMISSION ROUTE

Outbreak transmission type	Definition
Foodborne outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after consuming a common food or meal, and where analytical epidemiology or food microbiology implicates the food or meal as the source of illness
Suspected foodborne outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after consuming a common food or meal, and where compelling descriptive evidence from an epidemiological investigation and/or food safety inspection implicates the food or meal as the source of illness
Waterborne outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after exposure to a common water source (either drinking or recreational) and where analytical epidemiology or water testing implicates water as the source of illness
Suspected waterborne outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after exposure to a common water source (either drinking or recreational) and where compelling descriptive evidence from an epidemiological and/or environmental investigation implicates water as the source of illness
Person to person outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after exposure to a person or group of persons known or suspected to be infectious, or an environment where an infected person has been known to have contaminated and where illness onset dates suggest ongoing transmission
Animal to person outbreak	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after animal exposure and compelling descriptive epidemiological or environmental evidence and/or laboratory evidence implicates the animal as the source of illness
Unknown	An event where ≥ 2 persons are diagnosed with laboratory-confirmed campylobacteriosis after some common exposure but where a mode of transmission is unable to be determined
Unknown (revised)	An event where ≥ 2 persons are diagnosed with laboratory-confirmed <i>Campylobacter</i> infection after a common exposure but where a recognized mode of transmission is unable to be determined via either outbreak register detail and/or local review by a state or territory epidemiologist

TABLE 2. CHARACTERISTICS OF *CAMPYLOBACTER* OUTBREAKS BY TRANSMISSION ROUTES, AUSTRALIA 2001 TO 2016

Transmission route	No. outbreaks (% by route)	No. cases (% lab-confirmed)	Median no. cases (min. to max.)	No. hospitalizations (% cases)	No. deaths
Foodborne	51 (60.7)	723 (30.7)	10 (2 to 63)	51 (7.1)	2
Waterborne	5 (6.0)	104 (30.8)	22 (7 to 46)	5 (4.8)	0
Animal to person	2 (2.4)	16 (37.5)	8 (6 to 10)	1 (6.3)	1
Person to person	3 (3.6)	16 (81.3)	4 (3 to 9)	3 (18.8)	0
Unknown	23 (27.4)	183 (48.1)	6 (3 to 9)	12 (6.6)	0
Total	84 (100)	1042 (34.6)	7 (2 to 63)	72 (6.9)	3

cohort study, or case series), and levels of evidence obtained. Outbreak definitions were adapted from the Register's Data Dictionary (Version 1.5, December 2017) to describe outbreaks occurring through specific transmission routes (Table 1). Nominated food vehicles were grouped under the following categories: poultry-liver dishes; chicken kebabs; other chicken/chicken-containing dishes; chicken unspecified; other food vehicle; other poultry-meat; unpasteurized milk; and unknown food vehicle. For this dataset the term poultry is used in reference to domestic fowls, with poultry-liver referring to either chicken or duck and poultry-meat used in reference to duck alone. Other chicken/chicken-containing dishes describe food vehicles where chicken has been identified as the ingredient suspected of being contaminated (e.g., pasta dishes or dumplings). To examine trends in foodborne *Campylobacter* outbreaks we obtained annual totals for foodborne outbreaks reported between 2001 and 2016. Annual campylobacteriosis notification rates per 100,000 population were obtained from the National Notifiable Diseases Surveillance System (Australian Government Department of Health, 2019) for comparison against annual outbreak counts.

To provide greater etiologic certainty, outbreaks with a single laboratory-confirmed *Campylobacter* case or where additional enteric pathogens were detected were excluded. Also excluded were *Campylobacter* clusters. A cluster was defined as an increase in infections that are epidemiologically related in time, place, or person where investigations were unable to implicate a common mode of transmission or source of infection responsible for that increase (OzFoodNet Working Group, 2018).

Outbreak details were forwarded to state and territory foodborne disease epidemiologists, including queries regarding missing or potentially erroneous data. Epidemiologists were also asked to review local records to identify other outbreaks not identified in the Register, with this approach identifying one additional outbreak. We obtained separate details for nonfoodborne *Campylobacter* outbreaks from NSW and Victoria as both use local databases to record nonfoodborne outbreaks.

Each outbreak was assigned an evidence level based on published indicators of evidentiary strength for foodborne disease outbreaks (Moffatt *et al.*, 2016b). Options for evidence included the following: descriptive epidemiological evidence (hereafter called descriptive); statistical; laboratory and descriptive; descriptive and trace-back; laboratory and statistical; laboratory and trace-back; statistical and trace-back; and trace-back. For nonfoodborne outbreaks, options

referencing trace-back were not considered. Evidence levels were not assigned for outbreaks where the transmission route was unknown. If our reassessment of transmission differed to the original data, we asked state and territory epidemiologists to examine local records to assist with validation. If no compelling detail was available, our reassessment was adopted.

Data describing *Campylobacter* isolation in food and environmental samples were assessed and included detection in the following: unopened epidemiologically implicated food; opened epidemiologically implicated food; food consumed without epidemiological implication; other microbiological evidence; isolation from premises and equipment; no identification in laboratory samples; or no samples taken. A descriptive assessment of factors contributing to pathogen contamination and survival was also undertaken but excluded growth factors because of data paucity and a reduced likelihood for *Campylobacter* spp. to proliferate on foods (Park, 2002). Contributing factors to contamination of food or water included ingestion of contaminated raw product intended to be cooked, cross-contamination from raw ingredients, food handler contamination, storage in contaminated environment, ingestion of contaminated raw product intended to be consumed raw, or unknown. Contributing factors related to survival included insufficient time/temperature during cooking or reheating, inadequate disinfection, inadequate acidification, inadequate thawing and cooking, other process failure, or unknown. Evidence levels for contributing factors included assumed or suspected, confirmed through observation during inspection, confirmed verbally during inspection, confirmed with measured evidence, or unknown.

FIG. 1. Annual *Campylobacter* notification rates and outbreak counts, Australia, 2001–2016.

Data were analyzed using Microsoft Excel (Microsoft, 2013; Microsoft, Redmond, WA) and Stata SE version 13 (StataCorp, 2013; Stata Statistical Software: Release 13; StataCorp LP, College Station, TX). We used descriptive statistics, including chi-square tests for homogeneity and trend, to assess changes in the proportions of foodborne outbreaks reported over the study period. Examination of aged-care outbreaks used median tests to compare cases, hospitalizations, and outbreak duration between outbreaks classified with foodborne versus unknown transmission routes. The probability value for significance testing was ≤ 0.05 . Ethics approval was obtained from the Australian National University's Human Research Ethics Committee (Protocol: 2018/531).

Results

Between 2001 and 2016 we identified 84 *Campylobacter* outbreaks in Australia. Details on transmission route and associated disease burden are given in Table 2, with foodborne or suspected foodborne transmission (hereafter described as foodborne transmission or foodborne outbreaks) accounting for 61% (51/84) of outbreaks. Outbreaks were reported by all states and territories with the more populous states having higher outbreak counts (data not shown). Speciation detail was available for 44% (37/84) of outbreaks, with *Campylobacter jejuni* the dominant etiologic agent (35/37). Two outbreaks comprised mixed *Campylobacter coli* and *C. jejuni* infections. During this time annual notification rates for campylobacteriosis remained high, averaging >110 cases per 100,000 population. Conversely, the reported outbreak counts were small (median 5, min. 1 to max. 10), and varied between years (Fig. 1).

Characteristics of foodborne outbreaks by setting are given in Table 3. Among foodborne outbreaks, 39% (20/51) occurred in the setting of restaurants/cafes, followed by 16% (8/51) in ACFs, and 10% (5/51) in "other" settings, with the

latter including take-away food businesses (small-scale food venues providing made to order foods collected and eaten elsewhere by consumers). When compared with other transmission routes, associations with foodborne transmission were observed in restaurants ($\chi^2 = 16.99$ $p < 0.001$) and aged-care facilities (ACFs) ($\chi^2 = 7.41$ $p = 0.006$). Implicated foods were mostly prepared within the setting of the outbreak; however, five outbreaks involved foods prepared by commercial caterers, whereas molecular epidemiology linked another community outbreak to commercially produced chicken meat. Food vehicles were identified for 65% (33/51) of outbreaks, with poultry meat or offal implicated in 85% (28/33). Among these poultry-related food vehicles, liver dishes (e.g., pâté) comprised 39% (11/28), followed by other chicken-containing dishes (33%, 8/28), chicken kebabs (18%, 5/28), chicken unspecified (11%, 3/28), and duck (4%, 1/28). During the study period, OzFoodNet reported 2097 foodborne outbreaks (personal communication Rose Wright, February 13, 2019). After revising transmission route data, we determined that *Campylobacter* spp. accounted for 2.4% (51/2083) of foodborne outbreaks between 2001 and 2016. Although no significant trend in foodborne outbreaks caused by *Campylobacter* spp. was shown, we did observe a significant increase in the proportion of foodborne *Campylobacter* outbreaks linked to poultry-liver ($\chi^2 = 4.22$, $p = 0.04$). Among poultry-liver outbreaks, 73% (8/11) involved restaurants, 18% (2/11) involved commercial catering, whereas one outbreak involved pâté prepared in a private residence.

Nonfoodborne outbreak characteristics are given in Table 2. Before review, 11% (9/84) of *Campylobacter* outbreaks had an unknown transmission route. This increased to 27% (23/84) after we identified 14 outbreaks recorded as being foodborne but lacking the necessary evidence to meet the foodborne outbreaks definitions as given in Table 1. Among the most frequently identified settings for outbreaks with an unknown source were ACFs ($n = 10$), military facilities ($n = 4$), and private residences ($n = 4$). Among

TABLE 3. CHARACTERISTICS OF FOODBORNE *CAMPYLOBACTER* OUTBREAKS BY SETTING, AUSTRALIA 2001–2016

Outbreak setting	Foodborne outbreaks				
	No. outbreaks (all routes)	No. outbreaks (% foodborne)	No. cases (% lab-confirmed)	Median no. cases (min. to max.)	No. hospitalizations (No. deaths)
Restaurants	20	20 (100.0)	228 (28.9)	10 (2 to 35)	13
Aged care	22	8 (36.4)	143 (28.0)	14.5 (3 to 49)	10 (2)
Other settings ^a	5	5 (100.0)	85 (32.9)	5 (2 to 63)	1
Camps	7	3 (42.9)	43 (14.0)	14 (6 to 23)	0
Private residences	9	3 (33.3)	16 (50.0)	5 (4 to 7)	0
Schools	2	2 (100.0)	42 (38.1)	21 (6 to 36)	1
Other institutions	3	2 (66.7)	61 (14.8)	30.5 (5 to 56)	1
Picnics	2	2 (100.0)	8 (87.5)	4	0
Community	2	2 (100.0)	27 (100.0)	13.5 (3 to 24)	4
Military facility	5	1 (20.0)	19 (15.8)	19	19
Commercial caterer	1	1 (100.0)	11 (54.5)	11	1
Function	1	1 (100.0)	31 (12.9)	31	1
Workplace	1	1 (100.0)	9 (22.2)	9	0
Totals	81 ^b	51	723 (30.7)	10 (2 to 63)	51 (2)

^aIncludes three takeaway food establishments, a sporting club, and a dairy farm.

^bEighty-four outbreaks identified in total. Three nonfoodborne outbreaks occurred in settings not described above, that is, a child care center, a hospital, and an unknown setting.

TABLE 4. CHARACTERISTICS OF *CAMPYLOBACTER* OUTBREAKS REPORTED IN AUSTRALIAN AGED-CARE FACILITIES, 2001–2016

Transmission route	No. outbreaks (%)	No. cases (%)	No. lab-confirmed cases (%)	Median no. cases (min. to max.)	No. hospitalizations (total deaths)	Median outbreak duration in hours (min. to max.)
Unknown	10 (45.4)	82 (32.5)	35 (39.8)	6.5 (3 to 15)	3 (0)	72 (24 to 120) ^{a6}
Foodborne	8 (36.6)	143 (56.7)	40 (45.5)	14.5 (3 to 49)	10 (2)	72 (24 to 168) ^{a7}
Animal to person	2 (9.0)	16 (6.3)	6 (6.8)	8 (6 to 10)	1 (1)	144 ^{a1}
Waterborne	1 (4.5)	7 (2.8)	3 (3.4)	7 (–)	0 (0)	120 ^{a1}
Person to person	1 (4.5)	4 (1.6)	4 (4.5)	4 (–)	3 (0)	No data
Totals	22 (100.0)	252 (100.0)	88 (100.0)	8.5 (3 to 49)	17 (3)	96 (24 to 168) ^{a15}

^aNumber of outbreaks with data.

waterborne outbreaks ($n=5$), three occurred in camps, with single outbreaks in a child care center and an ACF. Rainwater tanks were identified as the source for four outbreaks, with a water bore the source for the fifth. Outbreaks involving person-to-person transmission were reported in an ACF, child care center, and private residence, whereas two outbreaks in a single ACF were linked to zoonotic transfer (Moffatt *et al.*, 2014).

Outbreaks were reported most frequently in ACFs, with 26% (22/84) occurring in this setting. Transmission source and associated disease burden for ACF outbreaks are given in Table 4. Among ACF outbreaks, 36% (8/22) involved foodborne transmission, whereas 45% (10/22) had an unknown transmission source. Foodborne outbreaks in ACFs were larger (median 14.5 cases) than those with an unknown transmission route (median 6.5 cases), whereas hospitalization frequency was significantly higher ($\chi^2=4.74$, $p=0.03$). Among foodborne outbreaks in ACFs, three-quarters (6/8) did not identify a food vehicle.

Examination of evidence levels obtained among the 73% (61/84) of outbreaks where a transmission route was determined showed 49% (30/61) utilized descriptive epidemiological evidence, 21% (13/61) statistical evidence, whereas 13% (8/61) used descriptive and statistical evidence in conjunction with microbiological findings. A further 10 outbreaks, including nine reported as foodborne, relied upon limited descriptive evidence, most often a common meal or restaurant exposure among cases but without a specific food vehicle being identified.

Data on food and environmental sampling conducted during investigations was available for 81 outbreaks, with 73% (59/81) of these investigations having no food or other samples collected for microbiological testing. For outbreaks involving sampling, 59% (19/32) yielded negative results, whereas 25% produced supportive evidence only (e.g., the presence of fecal indicator bacteria in a water sample). *Campylobacter* spp. were detected only four times in epidemiologically implicated foods, comprising chicken-liver pâté, duck livers, chicken wontons, and retail chicken meat. *Campylobacter* spp. was also recovered once from a rainwater tank supplying drinking water.

Investigators identified 57% (29/51) of foodborne outbreaks had one or more factors associated with pathogen contamination, whereas 47% (24/51) detailed factors relating to pathogen survival. Issues most frequently recorded were the ingestion of contaminated raw products intended to be cooked ($n=17$) and cross-contamination from raw ingredi-

ents ($n=14$), whereas for survival factors, insufficient temperature or cooking time was identified in 92% (22/24) of outbreaks. Most evidence used in determining contamination (83%, 24/29) and survival factors (71%, 17/24) were based on investigator assumption, as opposed to direct observation or measurement.

Discussion

Our study suggests that *Campylobacter* gastroenteritis outbreaks occur infrequently in Australia. Among outbreaks with recognized transmission sources, most were foodborne, with chicken or chicken-containing dishes the most commonly identified food vehicles. Although no rise in outbreaks over time was observed we did detect an increase in foodborne outbreaks involving poultry-liver. Other transmission sources seem to play a limited role in causing outbreaks in Australia. ACFs were the most frequently reported outbreak setting, whereas foodborne transmission occurred mostly in restaurants. A number of ACF outbreaks were reclassified to having an unknown transmission source, highlighting the challenges when gathering evidence to support inferences of foodborne transmission in that setting.

Despite robust food safety standards, Australia like many high-income countries, experiences significant disease burden because of *Campylobacter* spp. (Havelaar *et al.*, 2015; Moffatt *et al.*, 2017a). Despite this burden our results show a median of five outbreaks per year, with no increase in foodborne *Campylobacter* outbreaks as a proportion of all foodborne outbreaks over time. This infrequency of outbreaks relative to disease burden may be partly explained by *Campylobacter*'s innate physiology. Although invariably present on foods like raw poultry, the organism's fastidious growth requirements, coupled with sensitivity to environmental stressors limit its capacity to proliferate on food and survive cooking and freezing (Park, 2002). Similarly, international reporting shows *Campylobacter* contributes only a small proportion of the foodborne outbreak burden, although some increases are being reported. Between 2004 and 2008, the United States observed a two-fold increase (Geissler *et al.*, 2017), whereas in England the proportion of *Campylobacter* outbreaks increased significantly between 1992 and 2008, despite a decline in overall foodborne outbreaks (Gormley *et al.*, 2011). Such apparent differences with Australia could be attributed to variations in risk factors, transmission routes, surveillance and notification practices, or food regulation requirements.

Campylobacteriosis is recognized as a predominantly foodborne illness, with poultry being the major reservoir and the consumption and handling of poultry meat major risk factors (Skarp *et al.*, 2016). Globally, meat consumption has risen markedly over the past 20 years, driven largely by increases in poultry consumption, with Australians consuming >40 kg of poultry-meat per capita each year (Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) 2019). Consistent with this, our findings show a majority of outbreaks with a known transmission route were recorded as being foodborne, with chicken or poultry-containing meals the primary food vehicles. Although this study did not observe any increase in foodborne *Campylobacter* outbreaks *per se*, it did identify a significant increase in outbreaks linked to food vehicles such as pâté (Parry *et al.*, 2012; Moffatt *et al.*, 2016a), mirroring international outbreak reports implicating poultry-liver dishes (Little *et al.*, 2010; Lanier *et al.*, 2018). The ability of *Campylobacter* spp. to penetrate poultry livers through the hepatobiliary ducts (Whyte *et al.*, 2006), coupled with changes in eating habits and cooking practices (Jones *et al.*, 2016), provide a strong rationale for this observed increase.

Another food vehicle group responsible for outbreaks are unpasteurized dairy products. In the United States, these account for 69% of foodborne *Campylobacter* outbreaks (Geissler *et al.*, 2017), whereas we identified a single outbreak linked to unpasteurized milk, representing <2% of foodborne *Campylobacter* outbreaks. This discrepancy is explained by regulatory differences where in the United States, despite a federal ban on interstate commercial sales, numerous states permit sale of unpasteurized products within the state in which they were produced (Langer *et al.*, 2012). In contrast, Australia legally requires all milk and dairy products undergo pasteurization (or an equivalent process) to eliminate pathogenic microorganisms (Food Standards Australia and New Zealand (FSANZ), 2009), thus largely avoiding the issue.

Water sources are another recognized cause of *Campylobacter* outbreaks, with numerous large-scale events involving ground and surface water being reported throughout Europe, North America, and New Zealand (Moreira *et al.*, 2017). Although Australian estimates suggest 11% of campylobacteriosis cases are linked to water exposure (Gibney *et al.*, 2017), the majority of waterborne outbreaks have involved recreational exposure to *Cryptosporidium* infections (Dale *et al.*, 2010). Our study identified five waterborne outbreaks linked to drinking water, with four involving rainwater storage tanks and the fifth linked to bore water. Using rainwater tanks for household drinking water is common practice in Australia, particularly in rural and remote areas and the microbiological quality of such water is recognized as being less reliable (Environmental Health Committee (enHealth), 2011). Overall outbreak risk because of drinking water is probably low as a majority of Australians can access high-quality, regulated mains water; however, private supplies, particularly those utilizing rainwater storage tanks, carry some risk.

This study identified two outbreaks in an ACF involving probable zoonotic transmission through a puppy, highlighting a potentially emerging area of concern. Carriage and excretion of *Campylobacter* spp. in puppies and adolescent dogs is well-recognized (Hald *et al.*, 2004), whereas associ-

ations between human illness and puppy ownership have been demonstrated (Stafford *et al.*, 2007; Mughini Gras *et al.*, 2013). Although cognizant of the benefits of companion and therapy animals, the presence of puppies in such settings raises human health concerns (Moffatt *et al.*, 2014). Given our study has reported a number of ACF outbreaks without identified transmission sources we would encourage active efforts to exclude potential zoonotic transfer by scrutinizing age and species detail for all visiting or resident animals.

Our study shows ACFs to be the most common setting for *Campylobacter* outbreaks in Australia. Between 2001 and 2006, 18% (6/33) of outbreaks occurred in ACFs (Unicomb *et al.*, 2009), increasing to 26% (22/84) during our review period. Previously, *Campylobacter* spp. was shown to be the third highest cause of foodborne outbreaks in Australian ACFs (Kirk *et al.*, 2011). This contrasts with U.S. and UK data showing few foodborne aged-care outbreaks are attributed to *Campylobacter* spp. (Levine *et al.*, 1991; Ryan *et al.*, 1997). Such discrepancies could relate to a reporting bias, with all Australian states and territories requiring ACFs to report gastroenteritis outbreaks. Although this practice is well established in Australia, (Communicable Diseases Network Australia, 2010), potential underreporting of outbreak events should not be dismissed.

Although there are suggestions that higher rates of foodborne outbreak reporting in Australian ACFs may relate to more intensive investigation practices (Kirk *et al.*, 2012), our study shows a high proportion of these outbreaks lack evidence of foodborne transmission. Aged care is a challenging environment for investigations, with attempts to interview residents or retrospectively examine documentation leading to inconclusive findings (Winquist *et al.*, 2001). Our study shows food and environmental samples collected during outbreak investigations rarely result in *Campylobacter* spp. being detected, with this outcome in contrast to the relative successes achieved with trace-back sampling for *S. enterica* after egg-associated outbreaks in Australia (Moffatt *et al.*, 2017b). Given the proportion of ACF outbreaks with unknown transmission and their differing characteristics with outbreaks we have classified as foodborne, alternative transmission routes require consideration.

The Register has proved an invaluable tool in assisting varied public health and regulatory stakeholders with monitoring disease trends, developing policy and guiding food safety programs (Kirk *et al.*, 2008). We believe our liaison processes with states and territories, particularly requesting reviews of local records, have improved the quality of data presented, while addressing previous concerns regarding weak evidence and poor documentation of Register-derived data (Kirk *et al.*, 2011). A key aim of this study was to assess the quality of evidence used in assigning transmission routes, with the results showing that a number of outbreaks nominally recorded as being foodborne lacked the evidence to meet foodborne outbreak case definitions. Nevertheless differences in surveillance practices may have led to some foodborne outbreaks not being reported, with not all states and territories routinely contributing data to the Register until 2003. In addition, NSW only mandated the requirement to notify campylobacteriosis in 2017.

Public health capacity to routinely investigate even a small proportion of *Campylobacter* cases is currently constrained, with further difficulties imposed by the absence of a routine

subtyping system. However, a recent Danish study has shown whole genome sequencing may identify a higher degree of *Campylobacter* clustering and outbreak occurrence than previously thought (Joensen *et al.*, 2018). This illustrates the potential for this method as the basis for integrated surveillance routinely comparing human-derived isolates against those from established reservoirs. Although this could assist with detection of community-level outbreaks and the identification of sources within the primary production and processing sector, it remains possible that point-source foodborne outbreaks will remain uncommon because of *Campylobacter*'s physiology.

Conclusions

Campylobacter spp. remain a less commonly identified cause of gastroenteritis outbreaks in Australia. Although most outbreaks can be linked to foodborne transmission, including an increasing number caused by poultry-liver dishes, our study shows that gaps persist in evidence and knowledge around transmission. This is particularly evident for ACFs, where a higher frequency of outbreaks and an increased susceptibility of residents to poor health outcomes, mean efforts to better elucidate outbreak causes should be afforded a high priority.

Acknowledgments

The authors thank the following OzFoodNet Working Group members who have assisted with this study: Anthony Draper (Northern Territory), Neil Franklin (New South Wales), Kim Lilly (Hunter New England), Tasmania (Michelle Harlock), and Benjamin Witham (Western Australia).

Disclosure Statement

No competing financial interests exist.

Funding Information

The OzFoodNet Working Group is funded by the Australian Government Department of Health. C.M. has been supported by a National Health and Medical Research Council Public Health and Health Services Postgraduate Research Scholarship (APP107490). M.K. is supported by a National Health and Medical Research Council Fellowship (APP1145997).

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