Fly Transmission of *Campylobacter*

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An annual increase in *Campylobacter* infection in England and Wales begins in May and reaches a maximum in early June. This increase occurs in all age groups and is seen in all geographic areas. Examination of risk factors that might explain this seasonal increase identifies flies as a potential source of infection. The observed pattern of infection is hypothesized to reflect an annual epidemic caused by direct or indirect contamination of people by small quantities of infected material carried by flies that have been in contact with feces. The local pattern of human illness appears random, while having a defined geographic and temporal distribution that is a function of the growth kinetics of one or more fly species. The hypothesis provides an explanation for the seasonal distribution of *Campylobacter* infections seen around the world.

Campylobacter spp. are the most common bacterial causes of diarrhea in England and Wales (1). The epidemiologic features of *Campylobacter* infection have proved difficult to discover, and extensive strain typing has failed to clarify the main transmission routes. Testable hypotheses must be established to explain available evidence, particularly the reason for the observed seasonality. Relatively few outbreaks of *Campylobacter* gastroenteritis occur (2), and most cases are sporadic. In case-control and case-case studies of sporadic *Campylobacter* infections, most cases remain unexplained by recognized risk factors (3,4).

The annual increase in *Campylobacter* infections in England and Wales begins at approximately day 130 (May 9) and reaches a maximum at approximately day 160 (June 8) (Figure 1). Although this seasonal rise is seen in all ages, it is more marked in children (5). Cases in towns and cities across England and Wales show broadly similar seasonal changes in distribution (Figure 2). The relative geographic uniformity of the increase seen in May of most years has the temporal appearance of an annual national epidemic. Because person-to-person infection within the community is uncommon, it is likely that the epidemic is caused by a single main driver for human *Campylobacter* infection. The possible seasonal drivers were examined, and only vector transmission by flies appears to provide a convincing explanation for the observed seasonal trends (Table).

The seasonal increase in *Campylobacter* infections in May and June in England and Wales is hypothesized to reflect an annual epidemic caused by direct or indirect exposure of humans to contaminated material carried by several fly species that have been in contact with human, bird, or animal feces or contaminated raw foods. Flies have been shown to carry *Campylobacter* and can infect both humans and animals (6–8). Intervention studies have demonstrated diarrheal disease reduction linked to control of flies (9–11), and deaths from diarrheal diseases have been linked to measurements of fly abundance (12). The local pattern of human *Campylobacter* infection appears random, while having a defined geographic and temporal distribution. This distribution is predicted to be linked to the growth kinetics of 1 or more fly species and their access to environmental sources of *Campylobacter* in feces or food. The seasonal increase in fly populations results from rainy weather and an increase in temperature that causes the development from egg to fly to occur in days rather than months. Individual flies can lay hundreds

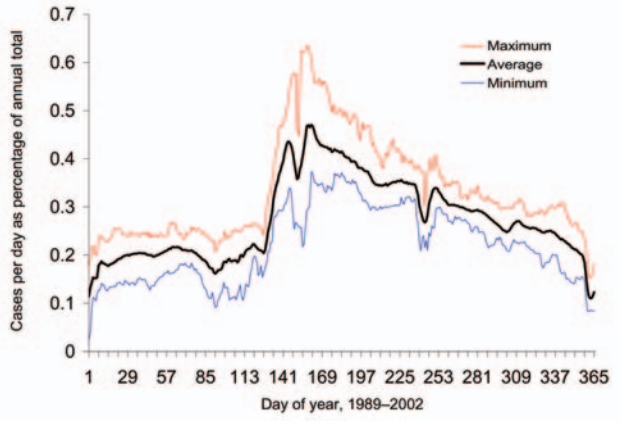

Figure 1. Distribution of *Campylobacter* cases per day. When averaged for 1989 to 2002, the epidemic begins at approximately day 130, peaks at approximately day 160, and gradually declines through the rest of the year.

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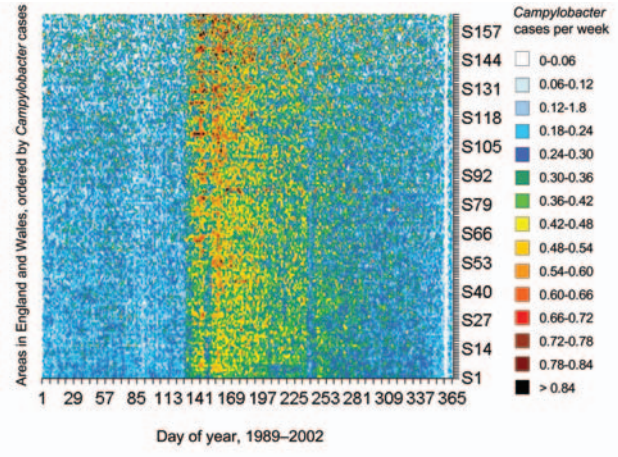

Figure 2. Cases of *Campylobacter* infection in England and Wales based on the patient specimen date. Figure shows broadly similar changes in patterns of infection across the country as measured by laboratory reporting per town or city (cases as a percentage of the annual total) by day of year. Laboratories were ordered by the total number of cases reported over the 14-year period (online Appendix available from http://www.cdc.gov/ncidod/EID/vol11no03/04-0460_app.htm).

of eggs, which can result in a large increase in fly numbers in a short period. Fly numbers fluctuate through the summer and decline in October, but the decline is less dramatic and defined than the spring increase.

Disease transmission is hypothesized to occur through small quantities of contaminated material carried on the feet, proboscis, legs, and body hairs or from material regurgitated or defecated by flies. The variety, numbers, virulence and viability of organisms in the contaminated material will differ, and some contamination will include *Campylobacter* while others will not. Contamination will be distributed over a variety of food types. Contamination of food by flies could occur at any stage of the food supply chain, but *Campylobacter* counts within the contaminated material on foods will decrease over time; consequently, most infection will result from contamination close to consumption (e.g., in the domestic or catering environment). Because whether a fly has visited contaminated feces is unknown and how a person becomes infected is uncertain, epidemiologic investigation is difficult.

A number of synanthropic fly species could be involved, including houseflies (e.g., *Musca* spp., *Fannia* spp.), blowflies (e.g., *Calliphora* spp., *Lucilia* spp.), and other dung-related flies (e.g., *Sarcophaga* spp., *Drosophila* spp.) (13). These flies have individual behavioral patterns, ecology, physiology, and temporal and geographic distributions that will influence the likelihood of their being in kitchens, on human or animal feces, and on food. Although *Musca domestica* is the species most likely to be involved because it is commonly found in houses and food-processing establishments, larger flies (e.g.,

Table. Risk factors that might affect *Campylobacter* seasonality*

Risk factor	Outbreaks	Evidence of seasonality	Credibility as the main seasonal driver
Barbecuing	Yes	Medium	Low
Birds	Yes	Strong	Low
Bottled water	No	None	Low
Chicken	Yes	Medium	Medium
Cross-contamination	Yes	None	None
Domestic catering	No	None	None
Farm visit	Yes	None	None
Farm animals	Yes	Weak	Low
Flies	No	Strong	High
Food handlers	Yes	None	None
Food packaging	No	None	None
Immunologic response	No	Weak	None
Mains supply drinking water	Yes	None	None
Nosocomial	Yes	None	None
Pets	No	Weak	Low
Pools, lakes, streams	No	None	None
Private drinking water supplies	Yes	Weak	None
Protozoa	No	None	Low
Salads and fruit	Yes	Weak	Low
Stir-fried food	Yes	None	None
The countryside	No	Weak	Medium
Transmission in families	Yes	None	None
Travel abroad	No	None	None
Unpasteurized milk	Yes	Weak	None
Weather/climate	No	Medium	Medium

*Evidence base provided in online Appendix (available from http://www.cdc.gov/ncidod/EID/vol11no03/04-0460_app.htm).

Calliphora spp.) may be able to transmit larger numbers of *Campylobacter*.

Flies contaminated through fecal contact will carry heterogeneous mixtures of organisms, including any pathogens that are present within the feces, and may be able to cause a variety of human infections, including infection by different *Campylobacter* species and types. This fact partially explains the lack of a clear epidemiologic picture arising from *Campylobacter* typing work. Gastrointestinal disease caused by flies is more likely to involve pathogens with a low infectious dose (e.g., *Shigella*, *Campylobacter*, *Cryptosporidium*, *Giardia*, *Cyclospora*, *Escherichia coli* O157), and some of these could have a seasonal component related to flies. Where high fly populations and poor hygiene conditions prevail, as in disasters or famines, or where pathogens can grow within fly-contaminated food, the potential exists for transmitting pathogens with a high infectious dose (e.g., *Vibrio cholerae*, *Salmonella* spp.). The access that flies have to human and animal feces will influence the degree to which they are contaminated with different enteric pathogens.

Contamination of a range of foods by flies will result in a pattern of infection that will not be amenable to identifying specific vehicles through standard case-control, case-case, or cohort studies, unless specific objective or subjective assessments of fly numbers can be obtained. Fly monitoring will need to be undertaken. An alternative approach could use estimates of fly population numbers based on climatic conditions to compare with data on human *Campylobacter* infections. This approach has the advantage of being able to use historical climatic and disease surveillance data. The broad relationship between *Campylobacter* cases and ambient temperature has not been explained in terms of disease causation. The time taken for the larvae of *M. domestica* to develop (13) was applied to temperature data for England and Wales and has been used to show a strong relationship between *Campylobacter* cases per week and *M. domestica* larval development time for 1989 to 1999 (Figure 3). Periods when *Campylobacter* cases exceed a 7-day average of 170 cases per day occurred when *M. domestica* larval development time was <3 weeks.

The hypothesis predicts that the *Campylobacter* infection rates will be higher in persons living close to animal production and lower in urban settings because fly numbers will be lower. Some evidence from the United Kingdom (1,14) and Norway (15) supports this hypothesis. Seasonal changes in *Campylobacter* incidence that are seen around the world may result from changes in fly populations and flies' access to human and animal feces. Much emphasis on foodborne disease reduction has rightly been on kitchen hygiene, since the low infectious dose of *Campylobacter* makes cross-transmission from raw meats

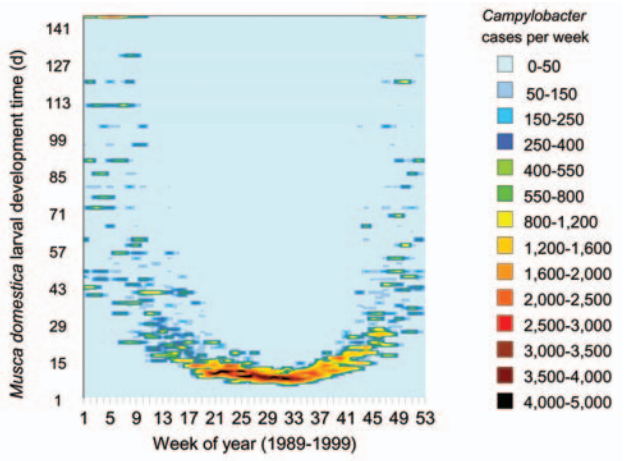

Figure 3. *Campylobacter* cases by week and *Musca domestica* larval growth times. *Campylobacter* cases per day are plotted against the minimum *M. domestica* growth times for the 14 days before the date for weeks from January 1989 to December 1999. The time taken for *M. domestica* larvae to develop was based on understood growth temperatures (145 days divided by the number of degrees above 12°C, up to an optimum of 36°C) (8). The temperatures were based on a maximum temperature in 47 temperature sampling sites across England and Wales in the 2 weeks before (online Appendix available from http://www.cdc.gov/ncidod/EID/vol11no03/04-0460_app.htm).

to ready-to-eat foods a substantial risk in domestic and catering environments. Fly transmission may be the most important source of infection in kitchen transmission routes, and establishments that sell ready-to-eat foods may be sources of *Campylobacter*, if effective fly control is not in operation. Flies may also be important in transmitting *Campylobacter* in poultry flocks (16) and between other agricultural animals.

While flies are regarded as important mechanical vectors of diarrheal disease in developing countries, control has largely concentrated on improving drinking water and sewage disposal. In the industrialized world, flies are thought to play a minor role in the transmission of human diarrheal diseases. Immediately intervening in the transmission of *Campylobacter* gastroenteritis should be possible through increased public awareness and more effective fly control.

Acknowledgments

This hypothesis arose after a lecture by Professor Sandy Cairncross at the Centers for Disease Control and Prevention, Atlanta, in the spring of 2002. I thank Fay Burgess, Radha Patel, Chris Lane, Douglas Harding, and Erol Yousef for help in preparing the data; Jim McLauchlin, Barry Evans, Chris Little, and John Edmonds for critically commenting on versions of the paper; and André Charlett for statistical support.

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