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An assessment of the human health impact of seven leading foodborne pathogens in the United States using disability adjusted life years

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SUMMARY

We explored the overall impact of foodborne disease caused by seven leading foodborne pathogens in the United States using the disability adjusted life year (DALY). We defined health states for each pathogen (acute illness and sequelae) and estimated the average annual incidence of each health state using data from public health surveillance and previously published estimates from studies in the United States, Canada and Europe. These pathogens caused about 112 000 DALYs annually due to foodborne illnesses acquired in the United States. Non-typhoidal *Salmonella* (32 900) and *Toxoplasma* (32 700) caused the most DALYs, followed by *Campylobacter* (22 500), norovirus (9900), *Listeria monocytogenes* (8800), *Clostridium perfringens* (4000), and *Escherichia coli* O157 (1200). These estimates can be used to prioritize food safety interventions. Future estimates of the burden of foodborne disease in DALYs would be improved by addressing important data gaps and by the development and validation of US-specific disability weights for foodborne diseases.

Key words: *Campylobacter*, foodborne infections, *Salmonella*.

INTRODUCTION

Foodborne diseases are an important public health problem in the United States, where each year 31 known pathogens cause an estimated 9·4 million illnesses, 56 961 hospitalizations, and 1351 deaths through contaminated foods [1]. Of these 31 known pathogens, norovirus was estimated to cause the most foodborne illnesses, while non-typhoidal *Salmonella* (NTS) was the leading cause of hospitalization and death. Overall, 90% of domestically acquired foodborne illnesses, hospitalizations, and deaths caused by known pathogens were attributed to seven pathogens: *Campylobacter, Clostridium perfringens, Escherichia coli* O157, *Listeria monocytogenes*, NTS, norovirus, and *Toxoplasma gondii.* These foodborne infections can also result in long-term complications and sequelae, the burden of which is substantial [2, 3].

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Understanding the overall human health impact of foodborne disease is important for prioritizing food safety policies and interventions. However, comparing multiple, distinct health outcomes across a range of foodborne diseases that cause a wide variety of different symptoms, complications, and long-term sequelae is challenging. The aim of this study was to explore the overall human health impact of foodborne disease caused by the seven leading foodborne pathogens in the United States using the disability adjusted life year (DALY), a measure developed by the World Health Organization that combines data on premature mortality and on morbidity from acute illness and sequelae into a single statistic summarizing years of healthy life lost [4].

METHODS

DALY

The DALY aggregates the loss of life and health due to illness compared with 'perfect' health, using time as the common metric [4].Therefore, the number of DALYs for all incident cases of illness caused by a specific foodborne pathogen can be calculated by summing the number of healthy years of life lost (YLL) due to premature mortality and the number of years lost due to disability (YLD) for each health state associated with that pathogen:

$$\mathrm{DALY} = \mathrm{YLL} + \mathrm{YLD}.$$

For each health state, the YLL is calculated by multiplying the number of deaths (D) by the remaining life expectancy at the age at which death occurs in years (E):

$$\mathrm{YLL} = \mathrm{D} \times \mathrm{E}.$$

YLD is calculated, for each health state, by multiplying the number of incident cases (N) by the estimated average duration of the health state (T) by a disability weight (DW) which reflects the severity of the disease. The disability weight is measured on a scale from 0 and 1, where perfect health is the best outcome (weight = 0), and death is the most severe outcome (weight = 1).

$$\mathrm{YLD} = \mathrm{N} \times \mathrm{T} \times \mathrm{DW}.$$

Health states

We defined health states for each pathogen (Supplementary Table S1) [2, 5–7]. The most common acute health state for *Campylobacter, C. perfringens, E. coli* O157, NTS, and norovirus was acute gastroenteritis, with severity ranging from mild illness (no medical care sought) to death. Sequelae included Guillain–Barré syndrome (GBS; from infection with *Campylobacter*), reactive arthritis (ReA; *Campylobacter* and NTS), post-infectious irritable bowel syndrome (PI-IBS; *Campylobacter* and NTS), and haemolytic uraemic syndrome (HUS) and end-stage renal disease (ESRD; *E. coli* O157). Important long-term sequelae were not considered to occur following infection with *C. perfringens* or norovirus. Two categories of infection with *Listeria* were considered. Health states of pregnancy-associated listeriosis included meningitis, bacteraemia, and neurological disorders, all in the neonate, as well as abortion or stillbirth, and neonatal death; health states of listeriosis not associated with pregnancy were meningitis, bacteraemia, and death. Similarly, two categories of infection with *Toxoplasma* were considered. Acquired toxoplasmosis was considered to result in mild or severe illness, chorioretinitis, and death. Sequelae of congenital toxoplasmosis included chorioretinitis, intracranial calcifications, hydrocephalus, and central nervous system abnormalities.

Data sources and approach

The average annual incidence of each health state was estimated using data from public health surveillance and previously published studies (Supplementary Table S2). When US data were not available, we used published studies from Europe or Canada. We used the incidence approach to estimating DALYs, in which disease burden is defined as the expected sum of current and future DALYs resulting from all incident cases of disease over a 1-year period. We assumed that all persons hospitalized would have previously sought medical care. We modelled the uncertainty in these estimates using @Risk (Palisades Corporation, USA) with probability distributions for all data inputs. When multiple data points were derived from published studies, we selected the middle value and used uniform minimum variance unbiased (UMVU) estimators to determine the minimum and maximum values. For proportions based on a single data point, we used a 50% relative increase/decrease on an odds scale to determine the minimum and maximum values. All model parameters and probability distributions are detailed in Supplementary Table S2.

Acute illness and death

For each disease, except congenital toxoplasmosis, we based our estimates of the average annual numbers of

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acute illnesses, hospitalizations, and deaths on previously published estimates by Scallan *et al.* of foodborne illness in the United States [1]. These estimates were based on statistical models using data from 2000 to 2008 and on the 2006 US population; therefore, the reference year for these estimates should be considered *circa* 2006. [1]. In generating posterior distributions for the purposes of this analysis, we used the negative binomial distribution with parameters chosen to approximate the distributions in the original paper (Supplementary Table S2).

All estimated *Campylobacter, C. perfringens, E. coli* O157, NTS, and norovirus illnesses, hospitalizations, and deaths were assumed to include acute gastroenteritis. The same statistical models used to estimate foodborne illness in the United States [1] were used to estimate the average annual number of ill persons who sought medical care for each pathogen, with the exception of norovirus, for which we used the estimated average annual rate of emergency room and outpatient visits for norovirus in the United States [8].

We used FoodNet surveillance data from 2005 to 2008 to estimate the proportion of listeriosis that was pregnancy-associated and applied that proportion to the estimated number of cases of invasive listeriosis from Scallan *et al.* [1], where a pregnancy-associated case was defined as isolation of *Listeria* from a pregnant woman, a fetus, or an infant aged <31 days. Data from the CDC's Listeria Initiative from 2005 to 2012 were used to estimate the proportion of pregnancy-associated illnesses that resulted in stillbirth and the proportions of live-born infants and patients with non-pregnancy-associated listeriosis who developed meningitis or bacteraemia. Meningitis and bacteraemia were defined as isolation of *Listeria* from cerebrospinal fluid (CSF) and blood, respectively.

For toxoplasmosis, we considered mild and severe illnesses as occurring in non-hospitalized and hospitalized persons, respectively. We estimated the annual number of cases of toxoplasmosis due to congenital infection in the United States based on an extrapolation of regional studies [9–11] and estimated the number of foodborne cases by applying the estimated proportion due to foodborne transmission [12, 13].

Sequelae

Guillain-Barré syndrome. We estimated the incidence of *Campylobacter*-associated GBS using European studies that linked surveillance data on laboratory-confirmed *Campylobacter* infections with hospital discharge registers or other medical records containing a GBS diagnosis. The rate of GBS was 20/100 000 *Campylobacter* cases in the UK [14], 23–30/100 000 in Sweden [15, 16], and 33/100 000 in Denmark [17]. We estimated the excess risk of GBS in *Campylobacter* cases by subtracting the expected rate in the US population (0·3/100 000) [18] from the estimated rate in *Campylobacter* cases. To estimate the number of deaths, we applied the case-fatality rate from all US GBS cases (2·2%) [18] to the estimated number of *Campylobacter*-associated GBS cases.

Haemolytic uremic syndrome. FoodNet data from 2000 to 2006 were used to estimate the average annual rate of *E. coli* O157-associated HUS [19]. We estimated the rate based on the number of HUS patients with culture-confirmed or serological evidence of *E. coli* O157 infection and applied it to the 2006 US population. The death rate in HUS patients was also derived from these data and applied to the estimated number of HUS cases. As post-diarrhoeal HUS cases would have been included in the estimated number of hospitalizations and deaths due to *E. coli* O157 infection [1], we subtracted the estimated number of HUS cases from estimates of acute gastroenteritis. For the proportion of HUS cases that progressed to ERSD we used an estimate (3%) based on data from a review of HUS patient studies [20].

Post-infectious irritable bowel syndrome. Our estimate of *Campylobacter* and NTS-associated PI-IBS was based on a meta-analysis of case-control studies [21]. We used the weighted mean (9%) of the estimated attributable risks and applied this to the estimated number of acute gastroenteritis illnesses for each pathogen.

Reactive arthritis. We based our estimates of *Campylobacter*-associated ReA (7%) on a Finnish population-based study that diagnosed ReA by physical examination and compared the incidence among case-patients with matched controls [22]. The proportion of persons with salmonellosis who developed ReA (8%) was based on a review of outbreaks [23]. We applied these proportions to the estimated number of physician visits for each pathogen. We based our estimate of medical care-seeking of ReA patients (44%) on a US study [24].

Sequelae of listeriosis. Estimates of the proportion of children who developed neurological disorders following pregnancy-associated listeriosis came from a case-series review [25].

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Table 1. *Estimated annual number of acute episodes of domestically acquired foodborne illness, overall and by heath state, for the five pathogens causing acute gastroenteritis* – Campylobacter, C. perfringens, E. coli *O157, non-typhoidal* Salmonella, *and norovirus illnesses, United States**

Pathogen	Domestically acquired foodborne illnesses				
	Total mean (90% CrI)	No medical care sought mean (90% CrI)	Sought medical care mean (90% CrI)	Hospitalizations mean (90% CrI)	Deaths mean (90% CrI)
Campylobacter spp.	845 000	619 800	216 800	8500	80
	(288 500–1 637 600)	(19 500–1 428 200)	(52 200–464 500)	(3700–14 800)	(3–230)
Clostridium perfringens	966 000	763 900	201 600	440	30
	(171 500–2 290 400)	(134 900–1 810 600)	(35 400–484 100)	(120–920)	(1–80)
Escherichia coli O157†	63 000	41 900	19 200	2000	10
	(11 000–149 600)	(0–129 000)	(11 700–28 000)	(410–4300)	(0–50)
Salmonella spp., non-typhoidal‡	1 027 600	797 600	230 000	19 300	380
	(576 200–1 584 300)	(334 000–1 366 100)	(147 300–324 200)	(6600–37 500)	(20–1100)
Norovirus	5 461 700	4 984 700	462 400	14 700	150
	(3 151 000–8 286 400)	(2 668 100–7 814 500)	(346 300–591 900)	(4000– 30 800)	(40–320)

CrI, Credible interval.
* Modal or mean value shown; numbers >1000 rounded to the nearest hundred, numbers from 10 to 1000 rounded to the nearest ten, numbers <10 not rounded.
† Excludes the estimated number of post-diarrhoeal haemolytic uraemic syndrome cases.
‡ Includes all *S. enterica* serotypes other than Typhi.

Sequelae of toxoplasmosis. Estimates of acquired toxoplasmosis-associated chorioretinitis were based on estimated rates of symptomatic retinitis in persons infected with *Toxoplasma* (0·3–0·7%) during an outbreak in Canada [26, 27]. The proportions of congenital toxoplasmosis cases that developed intracranial calcifications, CNS abnormalities, hydrocephalus, and chorioretinitis (with onset soon after birth and later in life) were based on a Dutch review of studies[5].

Disability weights

No disability weights were available from the United States for the relevant health states; therefore, we relied on disability weights from published Dutch studies (Supplementary Table S4). For acute gastroenteritis, we used Dutch disability weights generated using an annual profile method [28]. We accepted their disability weight of zero for mild gastroenteritis of 1 day or 5 days based on relevance criteria (more than 50% of their population panel was unwilling to trade time to be restored to full health).

YLL

To estimate YLL, we multiplied the estimated numbers of deaths by the population life expectancy at the age at which death occurred. The age distributions at time of death for persons with *Campylobacter, E. coli* O157, *Listeria*, and NTS infections were available from FoodNet surveillance from 1996 to 2012 (2000–2012 for persons with *E. coli* O157 who developed HUS) (Supplementary Table S3). YLL due to fetal and neonatal deaths were taken as the mean US life expectancy for males and females aged <1 year (78 years). For toxoplasmosis and GBS, data on age at death were obtained from the annual multiple cause-of-death data from US death certificates from 1999 to 2010. For *C. perfringens* illnesses, data on age at death were obtained from published case-series data and outbreak reports [29–31]. The number of deaths by age group for norovirus were estimated based on a published study [32]. Age-specific life expectancies were obtained from the 2006 US life tables for ages 0–99 years (Supplementary Table S3).

RESULTS

Incidence of health states

Table 1 shows the estimated annual number of acute episodes of domestically acquired foodborne illness for the five pathogens causing gastroenteritis – NTS,

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Table 2. *Estimated annual number of cases of sequelae, by pathogen, for episodes of domestically acquired foodborne illness, United States**

Pathogen	Cases of sequelae for episodes of domestically acquired foodborne illness, mean (90% CrI)
Campylobacter spp.	
Guillain–Barré syndrome	220 (70–440)
Deaths	5 (2–10)
Reactive arthritis	15 100 (3500–33 400)
Post-infectious irritable bowel syndrome	74 000 (24 600–147 000)
Escherichia coli O157	
Haemolytic uraemic syndrome	180 (160–200)
End-stage renal disease	6 (4–7)
Deaths	8 (6–10)
Listeria monocytogenes, pregnancy-associated	
Neurological complications in infant	9 (3–20)
Salmonella spp., non-typhoidal‡	
Reactive arthritis	18 400 (10 300–28 600)
Post-infectious irritable bowel syndrome	89 900 (48 800–141 700)
Toxoplamsa gondii, congenital	
Chorioretinitis, onset soon after birth	140 (40–260)
Chorioretinitis, onset later in life	20 (6–40)
Intracranial calcification	120 (30–210)
Hydrocephalus	20 (6–40)
Central nervous system abnormalities	40 (8–70)
Toxoplamsa gondii, acquired	
Chorioretinitis	2700 (1400–4400)

CrI, Credible interval.
* Modal or mean value shown; numbers >1000 rounded to the nearest hundred, numbers from 10 to 1000 rounded to the nearest ten, numbers <10 not rounded.
‡ Includes all *S. enterica* serotypes other than Typhi.

Campylobacter, E. coli O157, *C. perfringens*, and norovirus – including the number of medical care visits, hospitalizations, and deaths. We estimated 230 cases [90% credibility interval (CrI) 80–470] of pregnancy-associated listeriosis of which 50 (90% CrI 20–90) resulted in stillbirth. Of live-born infants, we estimated 90 (90% CrI 30–170) cases developed bacteraemia, 40 (90% CrI 10–80) developed meningitis, and 10 (90% CrI 0–30) infants died. Of 1360 (90% CrI 460–2600) cases not associated with pregnancy, we estimated that 1100 (90% CrI 380–2,160) developed bacteraemia, 210 (90% CrI 70–400) developed meningitis, and 250 (90% CrI 10–740) resulted in death. In addition to the 86 700 (90% CrI 64 600- 111 400) cases and 330 (90% CrI 200–480) deaths associated with acquired toxoplasmosis, we estimated 1100 (90% CrI 290–1900) foodborne congenital cases resulting in eight (90% CrI 2–20) deaths.

PI-IBS was the most common sequela from domestically acquired foodborne illness, with an estimated 89 900 and 74 000 cases attributed to NTS and *Campylobacter*, respectively (Table 2). ReA was the second most common sequela with 18 400 NTS- and 15 200 *Campylobacter*-associated cases. We estimated almost 2700 cases of chorioretinitis from acquired (93%) and congenital (7%) toxoplamosis.

DALY estimates

NTS (32 900) and *Toxoplasma* (32 700) caused the most DALYs due to domestically acquired foodborne illnesses (Table 3), followed by *Campylobacter* (22 500), norovirus (9900), *Listeria* (8800), *C. perfringens* (4000), and *E. coli* O157 (1200) (Table 3). YLL was the main driver of DALYs for *Listeria* (98%) and *E. coli* O157 (64%) (Fig. 1). YLD due to sequelae accounted for most of the DALYs for *Campylobacter* (74%), NTS (61%), *Toxoplasma* (59%). Of the YLD due to sequelae from toxoplasmosis, most were due to acquired cases of chorioretinitis. YLD from acute illness was the main driver of DALYs for *C. perfringens* (77%) and foodborne norovirus (76%).

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Table 3. *Estimated disability adjusted life years (DALYs) from domestically acquired foodborne illnesses, by pathogen, including the number of years lived with disability (YLD) and the number of years of life lost (YLL) due to mortality, United States**

	Domestically acquired foodborne illnesses					
	YLD		YLL		DALY	
Pathogen (estimated % foodborne†)	Mean	90% CrI	Mean	90% CrI	Mean	90% CrI
Campylobacter (80%)	20 100	8800–36 100	2300	200–6800	22 500	10 400-38 600
Acute gastroenteritis	3600	1100–7300	2,200	90–6,700	5800	2000–11 600
Reactive arthritis	960	220–2100	–	–	960	220–2100
PI irritable bowel syndrome‡	15 500	5200–30 900	–	–	15 500	5200–30 900
Guillain–Barré syndrome	50	20–110	100	20–210	150	40–310
Clostridium perfringens (100%)	3000	550–7200	900	30–2700	4000	1100–8400
Escherichia coli O157 (68%)	430	280–590	800	150–2200	1200	540–2600
Acute gastroenteritis	370	230–530	400	0–1800	760	80–2100
Hemolytic uremic syndrome	60	30–100	400	300–510	460	350–580
Listeria monocytogenes (100%)						
Pregnancy-associated	100	30–220	4,300	1500–8200	4400	1500–8400
Not associated with pregnancy	80	30–150	4,300	210–13 000	4400	300–13 100
Salmonella, non-typhoidal (94%)‡	24 300	15 500–35 400	8600	430–25 700	32 900	19 200–52 800
Acute gastroenteritis	4200	3000–5700	8,600	430–25 700	12 800	4400–29 900
Reactive arthritis	1200	620–1900	–	–	1200	620–1900
PI irritable bowel syndrome	18 900	10 300–29 900	–	–	18 900	10 300–29 900
Norovirus (26%)	7500	5700–9500	2400	630–5000	9900	7200–13 000
Toxoplamsa gondii (50%)						
Congenital	3900	1000–6900	630	160–1200	4500	1200–8100
Acquired	15 900	8400–25 700	12 300	7500–18 000	28 200	18 900–39 600

CrI, Credible interval; PI, post-infectious.

* Modal or mean value shown; numbers >1000 rounded to the nearest hundred, numbers from 10 to 1000 rounded to the nearest ten, numbers <10 not rounded.

† The estimated number of DALYs shown in this table are for domestically acquired foodborne illnesses only. Estimated percent foodborne from Scallan *et al.* [1].

‡ Includes all *S. enterica* serotypes other than Typhi.

DISCUSSION

We assessed the overall human health impact of foodborne disease from seven leading foodborne pathogens in the United States using the DALY approach, which allowed a ranking of pathogen-specific foodborne illness risks. NTS and *Toxoplasma* infections resulted in the highest number of DALYs each year due to domestically acquired foodborne illness, followed by *Campylobacter*, norovirus, *Listeria, C. perfringens*, and *E. coli* O157.

NTS has long been an important cause of foodborne illness in the United States, and the incidence of laboratory-confirmed infections reported to public health surveillance systems has remained relatively stable for almost a decade [33]. While NTS infection has a low case-fatality ratio compared to some other foodborne infections, such as *Listeria*, the high number of illnesses results in it being the leading cause of domestically acquired foodborne deaths among known pathogens, contributing to a number of YLL second only to foodborne toxoplasmosis. Nonetheless, most DALYs for *Salmonella* infection are due to years spent with disability, specifically time lived with PI-IBS. The assumption that symptoms last for an average of 5 years [34] was an important factor contributing to the high number of YLD attributable to PI-IBS.

Toxoplasma infects many persons in the United States, although most infections are asymptomatic or cause a self-limited illness [35]. However, in persons with immunocompromising conditions, such as human immunodeficiency virus or organ transplant, reactivated and untreated toxoplasmosis has a high mortality rate, and most of these deaths occur in

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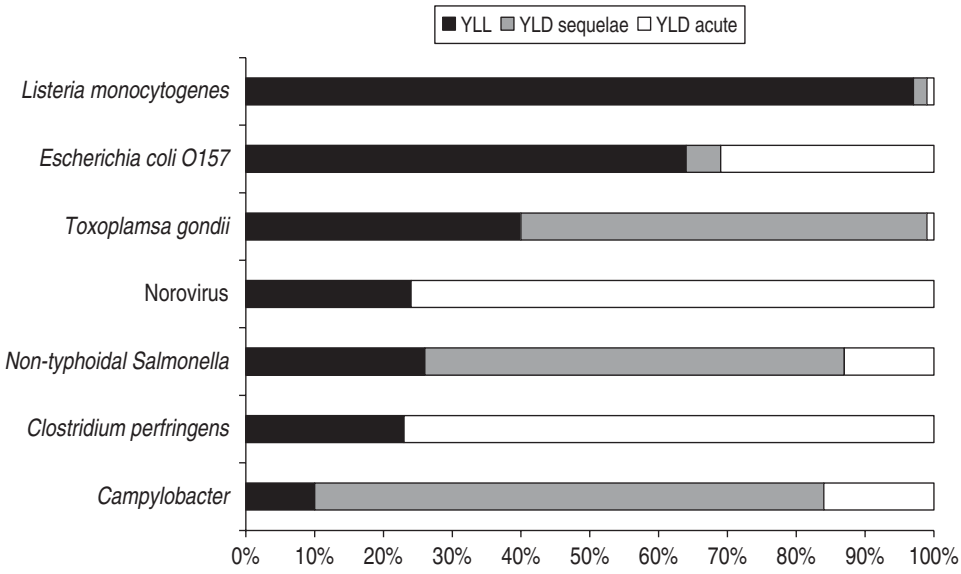

Fig. 1. Percentage of DALYs attributable to years of life lost (YLL) due to premature mortality and the number of years lost due to disability (YLD) from domestically acquired foodborne illnesses for seven leading foodborne pathogens, United States.

younger adults aged <65 years [36]. As such, premature death contributed 39% of DALYs for foodborne toxoplasmosis. We did not estimate the number of stillbirths that occurred due to congenital toxoplasmosis. Including these would have increased the number of premature deaths and the contribution of YLL to the total DALYs. The other main contributor to DALYs for foodborne toxoplasmosis is the years of life lived with chorioretinitis, an eye inflammation that can lead to severe visual impairment [27]. Public health efforts to reduce the incidence of foodborne toxoplasmosis have focused on improving meat quality and educating consumers about safe food handling [37].

The major drivers of DALYs varied by pathogen. Premature death was the most important contributor for *Listeria* and *E. coli* O157. *Listeria* has a high case-fatality rate in older adults, and pregnancy-associated cases can result in fetal loss or infant death. Most DALYs lost due to *E. coli* O157 were also due to YLL, because a high proportion of the deaths are in young children. DALYs lost due to foodborne norovirus and *C. perfringens* were mostly due to the large number of acute illnesses, each contributing only a small number of YLD but summing to a substantial burden. Similar to *Salmonella*, PI-IBS was the main driver of the number of DALYs lost for foodborne campylobacteriosis. Estimates of the prevalence of IBS in the general population of developed countries range from 10% to 20% [38, 39] of which 6–18% is estimated to be post-infectious [40]. Based on our estimates, prevalent cases of *Campylobacter*- and NTS-associated PI-IBS would account for about 2% of IBS in the United States.

Other studies assessing the relative importance of foodborne pathogens in the United States have resulted in similar rankings. Using quality adjusted life years (QALYs), another measure of disease burden that includes both the quality and the quantity of life lived, and cost of illness estimates, Hoffman *et al.* ranked NTS as the leading contributor to QALY losses due to 14 pathogens causing foodborne illness, followed by *Campylobacter, Toxoplasma, Listeria*, norovirus, and *E. coli* O157 [41], while Scharff attributed the largest economic burden to NTS followed by *Toxoplasma*, norovirus, *Listeria, Campylobacter*, and *E. coli* O157 [42]. In both studies, *C. perfringens* was ranked eighth, below *Yersinia*, which was not included in our study. In The Netherlands, using the DALY approach, *Toxoplasma, Campylobacter, Salmonella*, and *Staphylococcus aureus* toxins were responsible for the majority of the burden associated with foodborne disease due to 14 pathogens [2]. A study in New Zealand of DALYs attributable to six pathogens transmitted commonly through food ranked *Campylobacter* highest, followed by *Listeria*, norovirus, *Salmonella, Yersinia*, and STEC. [3]

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DALYs can vary markedly based on disability weights. For mild gastroenteritis, had we assigned the Dutch disability weight for 'Gastroenteritis, mild, 5 days' (0·010) rather than the weight based on relevance criteria (zero), norovirus would have ranked first rather than sixth in number of DALYs. However, had we assigned the Dutch disability weight for 'Gastroenteritis, mild, 1 day' (0·002), the rank order of pathogens would have remained unchanged.

These estimates have additional important limitations. There are important data gaps, especially with regard to sequelae. Therefore, we relied heavily on estimates from studies in other industrialized countries. Other possibly important sequelae for which conclusive demonstration of causality is lacking were not included in our estimates. For example, there is some evidence to suggest that inflammatory bowel disease, a term used to describe chronic intestinal diseases, primarily Crohn's disease and ulcerative colitis, can be triggered by bacterial enteric infections [43]. Moreover, there are reports of PI-IBS associated with norovirus [44]. We based our estimates of the average annual numbers of acute norovirus illnesses, hospitalizations, and deaths on estimates published by Scallan *et al*. in 2011 [1]; however, subsequent CDC publications have estimated a greater number of deaths attributable to norovirus [32]. In addition, we assumed that the age at death for foodborne norovirus was the same as that for all norovirus deaths. However, outbreak surveillance suggests that foodborne norovirus illnesses often involve younger adults compared to non-foodborne norovirus illnesses which more often affect the elderly. In generating posterior distributions for the estimated number of illnesses, hospitalizations, and deaths from the original CDC estimates of domestically acquired foodborne illness [1], we used the negative binomial distribution with parameters chosen to approximate the distribution in the original paper. The mean values generated were close to, and often exactly the same as, the estimates in the original paper; however, the variance did differ from the original estimates, particularly for deaths, which were often highly skewed. Because data on disability weights are lacking for US residents, we used weights from The Netherlands, although weights may vary between countries.

The most common causes of foodborne illness in the United States have tremendous costs in terms of morbidity and mortality. DALYs are one way to quantify these effects in a manner that allows comparison across illnesses caused by pathogens with different symptoms, complications, and sequelae. These analyses can help target preventive interventions to mitigate these effects. These estimates could be improved with better data distinguishing between mild, moderate, and severe disease; estimates of premature mortality that account for the impact of co-morbidities; and US-based estimates of disease sequelae. As additional data become available and as the incidence of illness changes, these estimates can be further refined.

SUPPLEMENTARY MATERIAL

For supplementary material accompanying this paper visit http://dx.doi.org/10.1017/S0950268814003185.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Scallan E, *et al.*** Foodborne illness acquired in the United States – major pathogens. *Emerging Infectious Diseases* 2011; **17**: 7–15.
2. **Havelaar AH, *et al.*** Disease burden of foodborne pathogens in the Netherlands, 2009. *International Journal of Food Microbiology* 2012: **156**: 231–238.
3. **Lake RJ, *et al.*** Risk ranking for foodborne microbial hazards in New Zealand: burden of disease estimates. *Risk Analysis* 2010; **30**: 743–752.
4. **Murray CJ, Lopez AD.** Global mortality, disability, and the contribution of risk factors: Global Burden of Disease Study. *Lancet* 1997; **349**: 1436–1442.
5. **Havelaar AH, Kemmeren JM, Kortbeek LM.** Disease burden of congenital toxoplasmosis. *Clinical Infectious Diseases* 2007; **44**: 1467–1474.
6. **Havelaar AH, *et al.*** Prioritizing emerging zoonoses in the Netherlands. *PLoS ONE* 2010; **5**: e13965.
7. **Kemmeren JM, *et al.*** Priority setting of foodborne pathogens: disease burden and costs of selected enteric

pathogens. Bilthoven: National Institute of Public Health and Environment, 2006
8. **Gastanaduy PA, *et al.*** Burden of norovirus gastroenteritis in the ambulatory setting – United States, 2001–2009. *Journal of Infectious Diseases* 2013; **207**: 1058–1065.
9. **Guerina NG.** Congenital infection with Toxoplasma gondii. *Pediatric Annals* 1994; **23**: 138–142, 147–151.
10. **Alford Jr. CA, Stagno S, Reynolds DW.** Congenital toxoplasmosis: clinical, laboratory, and therapeutic considerations, with special reference to subclinical disease. *Bulletin of the New York Academy of Medicine* 1974; **50**: 160–181.
11. **Kimball AC, Kean BH, Fuchs F.** Congenital toxoplasmosis: a prospective study of 4,048 obstetric patients. *American Journal of Obstetrics and Gynecology* 1971; **111**: 211–218.
12. **World Health Organization.** Toxoplasmosis, Technical Report Series, No. 431. Geneva: World Health Organization, 1969.
13. **Cook AJ, *et al.*** Sources of toxoplasma infection in pregnant women: European multicentre case-control study. European Research Network on Congenital Toxoplasmosis. *British Medical Journal* 2000; **321**: 142–147.
14. **Tam CC, *et al.*** Incidence of Guillain-Barre syndrome among patients with *Campylobacter* infection: a general practice research database study. *Journal of Infectious Diseases* 2006; **194**: 95–97.
15. **Ternhag A, *et al.*** Short- and long-term effects of bacterial gastrointestinal infections. *Emerging Infectious Diseases* 2008; **14**: 143–148.
16. **McCarthy N, Giesecke J.** Incidence of Guillain-Barre syndrome following infection with Campylobacter jejuni. *American Journal of Epidemiology* 2001; **153**: 610–614.
17. **Helms M, Simonsen J, Molbak K.** Foodborne bacterial infection and hospitalization: a registry-based study. *Clinical Infectious Diseases* 2006; **42**: 498–506.
18. **Frenzen PD.** Hospital admissions for Guillain-Barre syndrome in the United States, 1993–2004. *Neuroepidemiology* 2007; **29**: 83–88.
19. **Gould LH, *et al.*** Hemolytic uremic syndrome and death in persons with Escherichia coli O157: H7 infection, foodborne diseases active surveillance network sites, 2000–2006. *Clinical Infectious Diseases* 2009; **49**: 1480–1485.
20. **Garg AX, *et al.*** Long-term renal prognosis of diarrhea-associated hemolytic uremic syndrome: a systematic review, meta-analysis, and meta-regression. *Journal of the American Medical Association* 2003; **290**: 1360–1370.
21. **Haagsma JA, *et al.*** Disease burden of post-infectious irritable bowel syndrome in The Netherlands. *Epidemiology and Infection* 2010; **138**: 1650–1656.
22. **Hannu T, *et al.*** *Campylobacter*-triggered reactive arthritis: a population-based study. *Rheumatology (Oxford)* 2002; **41**: 312–318.
23. **Raybourne RB, Roberts T, Williams KM.** Food poisoning: economic implications. In: Caballero B, Trugo L, Finglas P, eds. *Encyclopedia of Food Sciences & Nutrition*. London, UK: Elsevier Science, 2003.
24. **Townes JM, *et al.*** Reactive arthritis following culture-confirmed infections with bacterial enteric pathogens in Minnesota and Oregon: a population-based study. *Annals of the Rheumatic Diseases* 2008; **67**: 1689–1696.
25. **Mylonakis E, *et al.*** Listeriosis during pregnancy: a case series and review of 222 cases. *Medicine (Baltimore)* 2002; 81: 260–269.
26. **Bowie WR, *et al.*** Outbreak of toxoplasmosis associated with municipal drinking water. *The BC Toxoplasma Investigation Team.* Lancet 1997; **350**: 173–177.
27. **Jones JL, Holland GN.** Annual burden of ocular toxoplasmosis in the US. *American Journal of Tropical Medicine and Hygiene* 2010; **82**: 464–465.
28. **Haagsma JA, *et al.*** Disability adjusted life years and minimal disease: application of a preference-based relevance criterion to rank enteric pathogens. *Population Health Metrics* 2008; **6**: 7.
29. **Sobel J, *et al.*** Necrotizing enterocolitis associated with clostridium perfringens type A in previously healthy north American adults. *Journal of the American College of Surgeons* 2005; **201**: 48–56.
30. **Bos J, *et al.*** Fatal necrotizing colitis following a foodborne outbreak of enterotoxigenic *Clostridium perfringens* type A infection. *Clinical Infectious Diseases* 2005; **40**: e78–83.
31. **Centers for Disease Control and Prevention.** Fatal foodborne *Clostridium perfringens* illness at a state psychiatric hospital – Louisiana, 2010. *Morbidity and Mortality Weekly Report* 2012; **61**: 605–608.
32. **Hall AJ, *et al.*** The roles of Clostridium difficile and norovirus among gastroenteritis-associated deaths in the United States, 1999–2007. *Clinical Infectious Diseases* 2012; **55**: 216–223.
33. **Centers for Disease Control and Prevention.** Vital signs: incidence and trends of infection with pathogens transmitted commonly through food – Foodborne Diseases Active Surveillance Network, 10 U.S. sites, 1996–2010. *Morbidity and Mortality Weekly Report* 2011; **60**: 749–755.
34. **Jung IS, *et al.*** The clinical course of postinfectious irritable bowel syndrome: a five-year follow-up study. *Journal of Clinical Gastroenterolgy* 2009; **43**: 534–540.
35. **Jones JL, *et al.*** *Toxoplasma gondii* infection in the United States, 199 92 004, decline from the prior decade. *American Journal of Tropical Medicine and Hygiene* 2007; **77**: 405–410.
36. **Jones JL, *et al.*** Risk factors for *Toxoplasma gondii* infection in the United States. *Clinical Infectious Diseases* 2009; **49**: 878–884.
37. **Jones JL, Dubey JP.** Foodborne toxoplasmosis. *Clinical Infectious Diseases* 2012; **55**: 845–851.
38. **Mertz HR.** Irritable bowel syndrome. *New England Journal of Medicine* 2003; **349**: 2136–2146.
39. **Hungin AP, *et al.*** The prevalence, patterns and impact of irritable bowel syndrome: an international survey of 40 000 subjects. *Alimentary Pharmacology and Therapeutics* 2003; **17**: 643–650.

40. **Spiller R.** Role of infection in irritable bowel syndrome. *Journal of Gastroenterology* 2007; **42** (Suppl.) 17: 41–47.
41. **Hoffmann S, Batz MB, Morris Jr. JG.** Annual cost of illness and quality-adjusted life year losses in the United States due to 14 foodborne pathogens. *Journal of Food Protection* 2012; **75**: 1292–1302.
42. **Scharff RL.** Economic burden from health losses due to foodborne illness in the United States. *Journal of Food Protection* 2012; **75**: 123–131.
43. **Garcia Rodriguez LA, Ruigomez A, Panes J.** Acute gastroenteritis is followed by an increased risk of inflammatory bowel disease. *Gastroenterology* 2006; **130**: 1588–1594.
44. **Zanini B, *et al.*** Incidence of post-infectious irritable bowel syndrome and functional intestinal disorders following a water-borne viral gastroenteritis outbreak. *American Journal of Gastroenterology* 2012; **107**: 891–899.