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Economic Burden of Major Foodborne Illnesses Acquired in the United States

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Sandra Hoffmann, Bryan Maculloch, and Michael Batz*

Abstract

Each year, approximately 48 million people become ill from foodborne illnesses in the United States. In only 20 percent of these cases (9.4 million illnesses) can a specific pathogen cause be identified; over 90 percent of these cases are caused by only 15 pathogens. This report summarizes recent estimates showing that these 9.4 million illnesses impose over $15.5 billion in economic burden annually. The report also provides "pamphlets" for each of these 15 foodborne pathogens that include: (1) a summary of information about the pathogen's foodborne illness incidence and economic burden relative to other foodborne pathogens; (2) a disease-outcome tree showing the number of people experiencing different outcomes caused by foodborne exposure to the pathogen in the United States each year; and (3) a pie chart showing the economic burden associated with different health outcomes resulting from infection with the pathogen. This report complements the ERS data product, Cost-of-Illness Estimates for Major Foodborne Illnesses in the U.S.

Keywords: Foodborne illness, cost of foodborne illness, economic burden of foodborne illness, health valuation, food safety, willingness to pay

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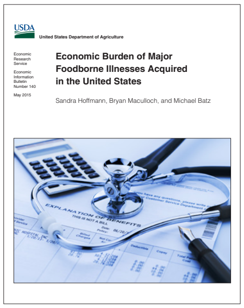

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Economic Burden of Major Foodborne Illnesses Acquired in the United States

Sandra Hoffmann, Bryan Maculloch, and Michael Batz

What Is the Issue?

Each year, one in six people in the United States is sickened by a foodborne illness. Government, industry, and others expend considerable resources in trying to prevent these foodborne illnesses. To best marshall these resources, food industry managers and policymakers need to know both the value of these efforts to society and how to target use of these resources. Estimates of the economic burden of illness provide a conservative measure of how much people are willing to pay to prevent these illnesses. This report provides an overview of recent estimates of the economic burden imposed annually by 15 leading foodborne pathogens in the United States. It also provides individual pathogen "pamphlets" that include:

- a description of the course of illness that can follow an infection with the pathogen;
- a summary of information about the pathogen's annual foodborne illness incidence and economic burden relative to other foodborne pathogens;
- a disease-outcome tree showing how many people experience different outcomes from foodborne exposure to the pathogen in the United States each year; and
- a pie chart showing the annual economic burden associated with different health outcomes resulting from infection with the pathogen.

What Did the Study Find?

Foodborne pathogens impose over $15.5 billion (2013 dollars) in economic burden on the U.S. public each year. Just five pathogens cause 90 percent of this burden. Estimates of economic burden per case vary greatly, ranging from $202 for *Cyclospora cayetanensis* to $3.3 million for *Vibrio vulnificus*.

- Fifteen pathogens cause 95 percent or more of the foodborne illnesses, hospitalizations, and deaths in the United States for which a specific pathogen cause can be identified. They are *Campylobacter* spp., *Clostridium perfringens, Cryptosporidium* spp., *Cyclospora cayetanensis, Listeria monocytogenes,* Norovirus, *Salmonella* non-typhoidal species, *Shigella* spp., STEC O157, STEC non-O157, *Toxoplasma gondii, Vibrio vulnificus, Vibrio parahaemolyticus, Vibrio* other non-cholera species, and *Yersinia enterocolitica*.
- Eighty-four percent of the economic burden from these 15 pathogens is due to deaths. This reflects both the importance the public places on preventing deaths and the fact that the measure of economic burden used for nonfatal illnesses (medical costs + productivity loss) is a conservative measure of willingness to pay to prevent nonfatal illness.

ERS is a primary source of economic research and analysis from the U.S. Department of Agriculture, providing timely information on economic and policy issues related to agriculture, food, the environment, and rural America.

- Pathogens' rankings by total economic burden generally follow their rankings by economic burden due to pathogen-related deaths, with notable exceptions. *Campylobacter* causes slightly more deaths per year than Norovirus, yet because of the very large number of nonfatal cases caused by Norovirus, its economic burden is higher than that of *Campylobacter*. The high medical costs and productivity losses caused by *Clostridium perfringens* contribute to its total economic burden exceeding those of three other pathogens with higher economic burden due to deaths (*Vibrio vulnificus*, *Yersinia enterocolitica*, and STEC O157).
- Estimates of the incidence of foodborne disease acquired in the United States, and therefore economic burden estimates, are very uncertain. The U.S. Centers for Disease Control and Prevention (CDC) estimates that the foodborne disease incidence from these 15 pathogens could range from 4.6 million to 15.5 million cases in a typical year. Based on this range of incidence estimates, economic burden could range from $4.8 billion to $36.6 billion (2013 dollars).

How Was the Study Conducted?

This report provides estimates of the costs of foodborne illnesses based on recently published journal articles. The estimates from that research, updated for inflation and income growth to 2013 values, are available in ERS's Cost-of-Illness Estimates for Major Foodborne Illnesses in the U.S. data product at http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx.

This report summarizes the findings from the ERS data product and provides additional educational materials based on the data product and journal articles targeted to a broad audience. The data product website allows users to explore the sensitivity of economic burden estimates to modelling assumptions. The data product also provides the information needed to update estimates for inflation and income growth over time.

The estimates underlying this report extend and update prior ERS cost-of-illness estimates by adding 11 pathogens and updating cost estimates for 4 other pathogens. These new estimates combine a cost-of-illness measure of economic burden for nonfatal illnesses and a willingness-to-pay measure for deaths. The estimates for new pathogens are based on a synthesis of data sources, including National Inpatient Sample data on hospitalization costs, and existing scientific literature. Estimates for all pathogens use 2011 CDC estimates of the incidence of foodborne illnesses acquired in the United States and associated hospitalizations and deaths. In modeling the likelihood of other health outcomes, the estimates rely on FoodNet data and reviews of scientific literature. In modeling the duration of illnesses and severity of health outcomes, the estimates rely on a review of clinical medical literature.

Economic Burden of Major Foodborne Illnesses Acquired in the United States

Introduction

Foodborne disease has many causes, including pathogens, allergens, and chemicals. The Centers for Disease Control and Prevention (CDC) estimates that each year, 1 in 6 people in the United States will be sickened by foodborne pathogens acquired in the United States.[1] Government, industry, and others devote considerable resources in trying to reduce these foodborne illnesses. For example, in 2014 Congress authorized over $2.2 billion in spending for Federal food safety programs.

To best marshall these resources, food industry managers and policymakers need to know both the cost and effectiveness of prevention efforts and their value to society. This report provides an overview of recent estimates of the economic burden imposed by major foodborne illnesses on the public. These economic burden estimates are a conservative measure of the value society places on preventing these illnesses. The information presented is drawn from a series of academic journal articles that have recently been updated and synthesized as a USDA, Economic Research Service data product (Batz et al., 2012; Batz et al., 2014; Hoffmann et al., 2012; USDA ERS, 2014). A more detailed documentation of the assumptions and methods used in these articles is available at http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx.

In recent years, media attention has centered on foodborne illnesses caused by pathogens. Pathogens are biological organisms—including bacteria, parasites, and viruses—that cause disease. Foodborne pathogens vary in the severity of the illnesses they cause and in their incidence (new cases per year), hospitalizations, and death rates. All the foodborne pathogens examined here cause diarrhea, and some cause vomiting. Some pathogens are more likely to result in bloody diarrhea or in sepsis, a potentially life-threatening complication from an infection. Occasionally, foodborne pathogen infections can result in longlasting health outcomes, including chronic kidney disease, recurring intestinal inflammation, reactive arthritis, blindness, and mental disability.

Estimates of the economic burden of illness reflect these differences in severity and provide a means of comparing burden across illnesses with very differing symptoms and outcomes.

[1]More information on the 2011 CDC foodborne illness incidence estimates can be found at http://www.cdc.gov/foodborneburden/.

An Overview of the Economic Burden of Major Foodborne Illnesses in the United States

Foodborne illness imposes a significant health burden on the U.S. population

The CDC estimates that each year roughly 48 million people in the United States become ill from a foodborne pathogen infection acquired in the United States (table 1). Of these, an estimated 128,000 are hospitalized and 3,000 die (Scallan et al., 2011a/b). Most of these illnesses are not reported to health authorities, and even when illnesses are reported, the cause is often not identified. As a result, the source pathogen is unknown for 80 percent of foodborne illnesses acquired in the United States each year (http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html).

Knowing the cause of illnesses helps public health officials and the food industry work more effectively to prevent them. CDC can link approximately 9.4 million episodes of foodborne illnesses a year to 31 identifiable pathogens (tables 1 and 3). These illnesses result in approximately 56,000 hospitalizations and 1,400 deaths each year (Scallan et al., 2011a). Over 95 percent of these illnesses, hospitalizations, and deaths due to known pathogen causes are caused by only 15 pathogens. We provide estimates of the economic burden of each of these 15 pathogens.

Table 1

Estimated annual number of domestically acquired foodborne illnesses, hospitalizations, and deaths due to 31 pathogens, United States

Foodborne agents	Estimated annual number of illnesses (90% credible interval)	%	Estimated annual number of hospitalizations (90% credible interval)	%	Estimated annual number of deaths (90% credible interval)	%
31 known pathogens	9.4 million (6.6–12.7 million)	20	55,961 (39,534–75,741)	44	1,351 (712–2,268)	44
Unspecified agents	38.4 million (19.8–61.2 million)	80	71,878 (9,924–157,340)	56	1,686 (369–3,338)	56
Total	47.8 million (28.7–71.1 million)	100	127,839 (62,529–215,562)	100	3,037 (1,492–4,983)	100

Source: CDC Estimates of Foodborne Illness in the United States, accessed at: http://www.cdc.gov/foodborneburden/2011-foodborne-estimates.html on Dec. 29, 2014.

Economic burden is a measure of the tradeoffs that people are willing to make to reduce illness

Economic burden of a disease is not the same thing as the impact of a disease on economic indicators like gross domestic product or even the out-of-pocket cost of treating illness.[2] Economic

[2]The economic burden of an illness depends on its frequency, severity, and health impact. For example, the Norovirus, which sickens millions of people each year, may have a high economic burden. But *Toxoplasma gondii*, which sickens far fewer people but has a high death rate, may have a higher economic burden. Also, people may feel differently about the same outcome with different causes. For example, research indicates that many people would pay more to avoid a death from cancer than a death from other causes (EPA, 2010; Viscusi, 2014).

burden measures the impact of disease on the welfare of all individuals in a society.[3] Conceptually, economists measure the economic burden of a disease as the sum of the willingness to pay by all individuals in society to reduce its incidence or likelihood. Reducing the risk of disease requires real resources (capital and time) that could be used to accomplish other goals, such as improving elementary education or providing for military defense. Knowing how people would allocate resources across different outcomes indicates how they rate one outcome's effect on their overall welfare relative to another. These real resources generally must be bought, or at least have value, in a market. For this reason, economists measure the impact of a *change* in an outcome on individuals' welfare by measuring their willingness to pay to secure or avoid that change.

Relative economic burden helps inform how best to prevent foodborne illnesses

Estimates of the economic burden of illness are used in a number of ways by different groups interested in foodborne illness. First, Federal regulatory agencies are required to conduct cost/benefit analyses of major new regulatory proposals (OMB, 2003), with both costs of regulatory compliance and health benefits from regulations measured in dollars. Second, public health officials, as well as regulatory agencies, use information on the relative economic burden of illnesses to guide nonregulatory management priorities. Nonmonetary measures, broadly referred to as Quality Adjusted Life Year (QALY) measures, are also used to compare the relative burden of illnesses (Hoffmann and Anekwe, 2013).[4] Finally, for some audiences, expressing the impact of illnesses in dollars provides a more meaningful measure of the impact of illnesses than physical outcomes like cases of illness or deaths.

Cost-of-illness estimates are a conservative approximation of the economic burden of illness

Ideally, economists would estimate the economic burden of illness by measuring individuals' willingness to pay (WTP) to reduce the risk of illness. This is not always practical. Many studies estimate individuals' WTP to reduce risk of illness or accident that results in death, but few estimate individuals' WTP to reduce risks of nonfatal illnesses. As a result, economists usually must approximate WTP to reduce non-fatal illnesses. It is important to know whether an approximation is an over- or underestimate of the thing that is being measured. Economic modeling shows that individuals' willingness to pay to reduce risk of illness is the sum of: (1) the cost of treating illness, (2) the value of time that cannot be spent on other valued activities because the individual is ill, (3) the pain and suffering involved with the illness, (4) expenditures on avoiding the illness, and (5) in some cases, the pain and suffering the illness causes others, particularly family members (Harrington and Portney, 1987).

The term "cost of illness" is sometimes used as shorthand for estimates of the economic burden of illness. More accurately, economists use the term to refer to approximations of willingness to pay for reductions in illness that include only financial losses (cost of treatment + lost wages resulting from illness and death). The estimates of the economic burden of foodborne illness in this report use cost-of-illness estimates for nonfatal illnesses and estimates of willingness to pay to reduce risk

[3]Economists refer to this as "welfare loss." Public health analysts use the term "disease burden" to refer to estimates of the burden of disease measured using a nonmonetary measure of the impact of disease, the Disability Adjusted Life Year (or QALY loss). Public health analysts refer to DALYs as a measure of welfare loss, but not in the sense economists use the term. To avoid confusion, we use the term "economic burden" to refer to welfare loss as used by economists.

[4]Because QALYs are nonmonetary measures, they cannot be directly compared with estimates of the economic burden of illness. Hoffmann et al. (2012) compare pathogen rankings based on the economic burden estimates and on QALY loss and find little difference in the rankings of the pathogens included in this report.

Measuring Willingness To Pay

WTP is an individual's willingness to pay for a good or service. Here, it refers to estimates of an individual's willingness to pay to reduce risk of either death or illness. In practice, WTP to protect health is measured either from market data—wage rates that vary by job risk or data on price/quantity of consumer products that vary in their safety risk—or survey data. Stated-preference health-valuation surveys either ask respondents whether they would buy a specific product/service that reduces health risks by a specific amount or ask them to choose among an array of such products or services that have different prices. Responses to these surveys can be used to estimate WTP to reduce risk of illness or death.

of death for fatal ones. Due to data limitations, we measure only the major costs of medical treatment, time lost to illness by the ill person that would have been spent earning wages or a salary, and individuals' willingness to pay to reduce risk of death. As a result, our estimates are a conservative measure of the economic burden that underestimates the full willingness of the U.S. public to pay to prevent these illnesses. The ERS report *Making Sense of the Costs of Foodborne Illness* provides a more detailed discussion of these issues (Hoffmann and Anekwe, 2013).

How we developed our economic burden-of-illness estimates

Our economic burden estimates draw on a wide range of information (table 2), synthesizing a variety of data and peer-reviewed literature. Estimation of the economic burden of illness involves two basic steps. First, disease-outcome trees are developed based on incidence estimates (new cases per year) and medical/epidemiological research. These trees show the share of all pathogen cases that result in different health outcomes. They trace the outcomes of an illness from infection to ultimate recovery or death. Second, the economic burden of each health outcome shown in the tree is estimated.

More detailed information on the data and assumptions used in developing the disease-outcome trees is provided in Batz et al. (2014). Detailed descriptions of the data and assumptions behind these estimates of the economic burden of foodborne illnesses are provided in Hoffmann et al. (2012).

Estimating Physical Outcomes

The foundation for all economic-burden-of-illness estimates is the estimated incidence of disease. We use recent CDC estimates of the incidence of illness, hospitalization, and deaths for each pathogen (Scallan et al., 2011a). These data are supplemented by information from the scientific literature on the likelihood of other health outcomes. For most pathogens included in this report, we look at five basic health outcomes:

- Non-hospitalized cases that do not require medical care;
- Non-hospitalized cases that require medical care;
- Hospitalized cases of varying severity;
- Chronic illness, where data support estimation of the economic burden of chronic conditions; and
- Deaths.

Table 2
Factors included in economic burden of illness estimates

Factors influencing economic burden of illness/welfare impacts of illness	Factors included in: Willingness to pay to reduce risk of illness	Cost of illness
Cost of treatment	X	X
Value of time lost to illness	X	X
Pain and suffering of the ill	X	
Expenditures on avoiding illness	X	
Pain and suffering of people other than the person who is ill	X	

Source: USDA, Economic Research Service.

The research that this report draws on was designed to update and extend existing ERS estimates of the economic burden of specific foodborne illnesses. ERS's old Cost of Foodborne Illness Calculator included estimates for *Salmonella* spp. (nontyphoidal), STEC O157, *Listeria monocytogenes*, and *Campylobacter* spp. (http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx).[5] For these four pathogens, the new CDC estimates of disease incidence and hospitalization/fatality rates were used to update disease-outcome trees. For the remaining 11 pathogens, new disease-outcome trees were developed using CDC incidence estimates, other national data sets, and a review of the scientific literature. Where available, the average length of a hospital stay was taken from the Nationwide Inpatient Sample (NIS) database for 2001-03, using International Classification of Diseases, Ninth Revision (ICD-9) codes to identify pathogen-specific diagnoses.

U.S. studies and data were used to estimate physical outcomes of foodborne illness where available. U.S.-specific information was not available for congenital toxoplasmosis. The disease-outcome tree branch for congenital infections with *Toxoplasma gondii* used estimates of the likelihood of health outcomes resulting from *Toxoplasma* infections in the Netherlands, which are then applied to CDC disease-incidence estimates.

Because they are longlasting, chronic conditions can pose significant economic burden if they are serious. Research into the chronic consequences of infectious diseases is ongoing. We include conditions for which there was adequate research to quantify the incidence of chronic conditions caused by the pathogens included in this report. As research on this issue proceeds, more chronic conditions may be included in future estimates of the burden of foodborne illness.

Long-term disabilities, chronic conditions, and latent impacts of acute foodborne illness are not included in CDC's recent estimates of foodborne illness (Scallan et al., 2011a). We include Guillain-Barré syndrome (GBS) for *Campylobacter*, diarrhea relapse for *Cryptosporidium* spp., end-stage renal disease (ESRD) for STEC O157 and non-O157, vision loss for *Toxoplasma gondii*, and numerous impacts of congenital infection from *Toxoplasma* and *Listeria* such as stillbirths, neonatal

[5]Formal scientific names include both genus and species. We use simplified names in this report once we have introduced a new pathogen with its full scientific name. For example, in the remainder of this report, nontyphoidal species of *Salmonella* will be referred to simply as *Salmonella, Campylobacter* spp. as *Campylobacter, and Listeria monocytogenes* as *Listeria. S*cientific names change as more is learned about organisms. STEC O157 is a new name for *E. coli* O157:H7.

deaths, and lifelong physical and mental disabilities. We do not include other known long-term health outcomes—including reactive arthritis and irritable bowel syndrome—based on recommendations from a scientific advisory committee that evidence was not strong enough to support estimates of the number of cases with these outcomes.

Estimating the Cost of Acute, Non-Fatal Outcomes

Estimates for disease outcomes and costs of medical treatment and productivity loss for non-fatal *Salmonella*, STEC O157, *Listeria*, and *Campylobacter* were based on prior ERS cost estimates adjusted to reflect 2011 CDC incidence/hospitalization estimates and updated to 2013 for inflation and real income growth. The methods used to develop estimates of the cost of other non-fatal illnesses were designed to be consistent with methods used in prior ERS cost-of-illness estimates (ERS, 2014; Buzby et al., 1996a; Buzby et al. 1996b; Buzby et al., 1997; Frenzen et al., 1999; Frenzen, 2003; Frenzen, 2004; Frenzen et al., 2005; Golan, 2005; Frenzen, 2007; Frenzen, 2008; Roberts, 2007).

Medical Treatment Costs of Non-Hospitalized Cases

Mild and moderate cases of foodborne illness are assumed to have the same daily health care use and costs as mild and moderate illness caused by *Salmonella*. Daily costs are multiplied by pathogen-specific illness durations.

Prior ERS estimates found that the cost of prescription and over-the-counter medication used to treat non-hospitalized cases of *Escherichia coli* (*E. coli*) O157 were only 2 percent of the total cost of illness for this pathogen. For other pathogens, little data were available on the cost of medications for non-hospitalized cases. Given the small contribution such costs made to the total cost of treating non-hospitalized *E. coli* O157 cases, medication costs were not included for non-hospitalized cases of other pathogens. This modeling choice adds to the conservative nature of our estimates.

Hospitalization Costs

For *Cryptosporidium* spp., Norovirus, *Shigella* spp., *Toxoplasma gondii*, and *Yersinia enterocolitica*, costs of hospitalization are the means of hospitalization costs from the NIS database for 2001-03, based on matching ICD-9 codes for primary diagnosis. The remaining six pathogens not included in the old ERS Cost-of-Illness Calculator did not have sufficient coverage in the NIS to develop pathogen-specific estimates of hospitalization costs, so per-visit hospitalization costs were estimated on the basis of diseases with similar symptoms and severities. Costs per hospitalization for STEC non-O157 illnesses were assumed to be the same as those for *E. coli* O157. Similarly, costs per hospitalization for illnesses caused by *Cyclospora cayetanensis* were assumed to be the same as those for *Cryptosporidium*, those for illnesses from *Clostridium perfringens* infections the same as those for Norovirus, and those for illnesses caused by *Vibrio* (other non-cholera species) the same as those for *Salmonella*. *Vibrio vulnificus* hospitalization costs were based on those for *Listeria monocytogenes*, adjusted for differences in rates of intensive care admittance.

For all pathogens, hospitalized cases were assumed to have additional medical costs including physician, emergency room, and outpatient services. These were modeled as equivalent to medical costs incurred from salmonellosis.

Productivity loss

Cost-of-illness estimates need to reflect the opportunity cost of time spent being ill. In principle, both the opportunity cost of time of the ill person and value of the non-compensated time spent caring for the ill should be measured. Due to lack of data on the age distribution of illness for most pathogens, we cannot model the number of cases requiring at home care by other family members. Thus, we include only the time lost by the infected person to foodborne illness. As is done in most cost-benefit analysis, we use lost wages as a measure of the opportunity cost of time spent being ill. This is a conservative measure of the opportunity cost of the time spent being ill because it does not include the value of time spent in uncompensated activities, like work around the house or leisure. We estimate productivity loss for each health outcome as the product of days of work lost per case and average daily wage rate, adjusted for the employment rate. Hoffmann et al. (2012) and Hoffmann and Anekwe (2013) provide more detailed discussion of this issue.

Estimating the cost of chronic illnesses and disabilities

Medical costs and productivity losses from congenital listeriosis, physical and mental disabilities resulting from *Campylobacter*-associated GBS, and ESRD following infection with STECs are based on existing cost-of-illness studies. Per-case costs of diarrhea relapse following illness due to *Cryptosporidium* are assumed equivalent to costs for a mild, acute case of diarrhea. Although we were able to develop a disease-outcome tree for congenital toxoplasmosis, we did not find sufficient data or research on medical costs or productivity losses to include it in our economic burden estimates.

Estimating willingness to pay to reduce risk of deaths

Economic research valuing efforts to prevent deaths is evolving. In valuing the economic burden of mortality, most Federal agencies use a measure of willingness to pay to reduce risk of death called the Value of a Statistical Life (VSL). Prior ERS cost-of-foodborne-illness estimates used an annuitized form of the VSL called the Value of a Statistical Life Year (VSLY). The VSLY is calculated by assuming that the VSL represents a stream of equal payments over the average expected life span of those in studies on which the VSL is based. ERS then used the VSLY to value expected years of life lost due to foodborne illnesses based on average U.S. life expectancy. Economists debate whether the assumptions underlying the use of a constant VSLY to value years of life lost are accurate. Currently, most Federal agencies use an age-invariant VSL to value mortalities rather than a VSLY to value years of life lost. Hoffmann and Anekwe (2013) review the economics literature that led to this change in practice. We value each death the same, using a VSL of $8.7 million (in 2013 U.S. dollars) based on a U.S. Environmental Protection Agency (2010) review of existing estimates. The value of preventing future deaths following chronic illnesses was discounted back to present value using a 3-percent discount rate.

> The value of a statistical life (VSL) is individuals’ willingness to pay for small changes in their risk of death divided by the change in risk. If WTP for a 1-in-10,000 reduction in risk of death is $600, the VSL is $6,000,000. The term a “statistical life” refers to the fact that while for an individual, there is a reduction in risk of death, in aggregate (across a population) this leads to an expected reduction in deaths over the time period.

Prior ERS estimates also assumed that 60 percent of neonatal deaths, stillbirths, and miscarriages would be replaced by siblings who fully compensate for the earlier loss and therefore include only 40 percent of such losses in cost-of-illness estimates. The White House Office of Management and Budget now directs Federal agencies to use values for children that are at least as high as for adults unless there is "specific and compelling evidence to suggest otherwise" (OMB, 2003). As we know of no WTP studies for neonatal deaths, stillbirths, and miscarriages, we value these outcomes using the same VSL as used for other deaths. This assumption is less conservative than that used in prior ERS estimates.

Comparing economic burden across pathogens

Two results stand out from recent research on the incidence of foodborne illness and our research on the cost of foodborne illnesses in the United States. First, we know little about what is causing the vast majority of foodborne illnesses; 80 percent of foodborne infections do not have identifiable causes. This gap in knowledge indicates the need for research on the cost and value of investment in better foodborne disease surveillance. Second, for those illnesses for which a pathogen cause can be identified, most of the cases, hospitalizations, and deaths are caused by relatively few pathogens. The 15 pathogens included in this report cause over 95 percent of the illnesses, hospitalizations, and deaths from foodborne illnesses acquired in the United States for which a pathogen cause can be identified (table 3).

A comparison of the economic burden of the 15 pathogens included in this study underscores the importance of an even smaller number of pathogens in determining the economic burden of foodborne disease in the United States. Five pathogens (*Salmonella, Toxoplasma gondii, Listeria monocytogenes, Campylobacter*, and Norovirus) cause over 90 percent of the total economic burden from these pathogens (table 4). Seven pathogens, the five just mentioned plus *Vibrio vulnificus* and *Yersinia enterocolitica*, cause over 94 percent of the total economic burden from the 15 pathogens (fig. 1).

Our analysis also allows us to look at the health outcomes that are causing the greatest economic burden: 83 percent of the economic burden from these 15 pathogens is due to deaths (fig. 2). This in part reflects the fact that cost of illness (medical costs + productivity loss) is a conservative approximation of willingness to pay to prevent nonfatal illness, but it also reflects the importance to the public of preventing deaths.

Figure 3 sorts pathogens by willingness to pay to prevent the deaths that are caused by each pathogen in a typical year. Pathogens' rankings by total economic burden estimates are generally similar to their rankings by willingness to prevent pathogen-related deaths. This is not always the case. For example, *Campylobacter* causes slightly more deaths per year than Norovirus, but because of the very large number of cases caused by Norovirus, its economic burden is higher than that of *Campylobacter.* Medical costs and productivity losses contribute significantly to the total cost of Norovirus cases (fig. 3a). Similarly, the higher medical costs and productivity losses caused by *Clostridium perfringens* contribute to its total economic burden exceeding those of three other pathogens with higher willingness to pay to prevent deaths (*Vibrio vulnificus, Yersinia enterocolitica, and* STEC O157) (fig. 3b). Knowing what is causing economic burden is of practical importance. For example, over the past 10 to 15 years, a concerted, focused effort to advance diagnosis and treatment of STEC O157 infections has resulted in a reduction in death rates from these infections.

Table 3

Incidence of domestically acquired foodborne illnesses in the United States with identified pathogen cause

	Mean Incidence			Percentage *		
	Cases	Hospitalizations	Deaths	Cases	Hospitalizations	Deaths
15 pathogens included in ERS estimates:						
Campylobacter, all species	845,024	8,463	76	9.0	15.1	5.6
Clostridium perfringens	965,958	438	26	10.3	0.8	1.9
Cryptosporidium, all species	57,616	210	4	0.6	0.4	0.3
Cyclospora cayetanensis	11,407	11	0	0.1	0.0	0.0
Listeria monocytogenes	1,591	1,455	255	0.0	2.6	18.9
Norovirus	5,461,731	14,663	149	58.2	26.2	11.0
Salmonella, all non-typhoidal species	1,027,561	19,336	378	10.9	34.6	28.0
Shigella, all species	131,254	1,456	10	1.4	2.6	0.7
STEC 0157	63,153	2,138	20	0.7	3.8	1.5
STEC non-0157	112,752	271	0	1.2	0.5	0.0
Toxoplasma gondii	86,686	4,428	327	0.9	7.9	24.2
Vibrio vulnificus	96	93	36	0.0	0.2	2.7
Vibrio parahaemolyticus	34,664	100	4	0.2	0.1	0.6
Vibrio, other non-cholera species	17,564	83	8	1.0	1.0	2.1
Yersinia enterocolitica	97,656	533	29	1.0	1.0	2.1
16 other identified pathogen causes	473,362	2,283	29	5.0	4.1	2.1
Total	9,388,075	55,961	1,351	100	100	100

*Percentages do not add to 100 percent due to rounding.

Source: Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson M-A, Roy SL, et al. Foodborne illness acquired in the United States—major pathogens. Emerg Infect Dis [serial on the Internet]. http://dx.doi.org/10.3201/eid1701.P11101 accessed Dec. 29, 2014.

Table 4

Economic burden of 15 leading foodborne illnesses acquired in the United States, by pathogen (2013 $)

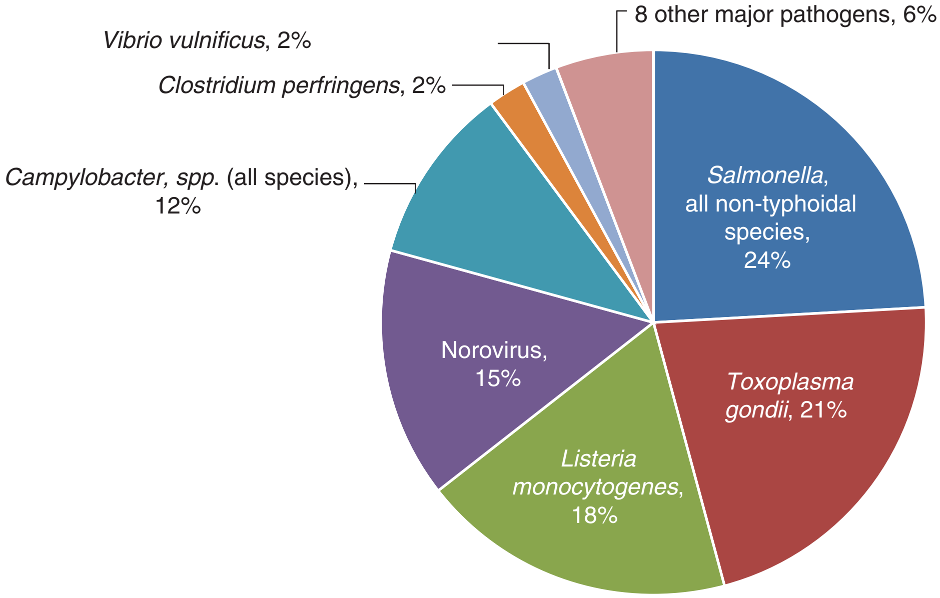
	Medical costs (percent of total cost for the pathogen)	Productivity loss (percent of total cost for the pathogen)	Deaths (percent of total cost for the pathogen)	Total (pathogen total as percent of total across 15 pathogens)	
				Dollars	Percent
Campylobacter, all species	$284,932,100 (15%)	$237,467,416 (12%)	$1,406,387,650 (73%)	$1,928,787,166 (100%)	12%
Clostridium perfringens	$53,247,647 (16%)	$64,329,568 (19%)	$225,091,283 (66%)	$342,668,498 (100%)	2%
Cryptosporidium, all species	$7,805,136 (15%)	$9,379,088 (18%)	$34,629,428 (67%)	$51,813,652 (100%)	0%
Cyclospora cayetanensis	$842,184 (37%)	$1,459,239 (63%)	NA	$2,301,423 (100%)	0%
Listeria monocytogenes (adult and congenital)	$138,211,033 (5%)	48,410,168 (2%)	$2,647,823,002 (93%)	$2,834,444,202 (100%)	18%
Norovirus	$597,916,921 (27%)	367,964,199 (16%)	$1,289,946,198 (57%)	$2,255,827,318 (100%)	15%
Salmonella, all nontyphoidal species	$312,738,453 (9%)	$81,380,620 (2%)	$3,272,480,959 (93%)	$3,666,600,031 (100%)	24%
Shigella, all species	$42,130,731 (31%)	$9,261,661 (7%)	$86,573,570 (63%)	$137,965,962 (100%)	1%
STEC non-O157	$14,277,961 (52%)	$7,285,748 (27%)	$5,800,852 (21%)	$27,364,561 (100%)	0%
STEC O157	$34,619,998 (13%)	$5,643,034 (2%)	$231,155,658 (85%)	$271,418,690 (100%)	2%
Toxoplasma gondii	$328,441,145 (10%)	$11,264,285 (0%)	$2,964,279,048 (90%)	$3,303,984,478 (100%)	21%
Vibrio, other non-cholera species	$2,177,769 (3%)	$1,390,727 (2%)	$69,258,856 (95%)	$72,827,353 (100%)	0%
Vibrio parahaemolyticus	$3,376,139 (8%)	$2,676,745 (7%)	$34,629,428 (85%)	$40,682,312 (100%)	0%
Vibrio vulnificus	$7,970,516 (2%)	$214,923 (0%)	$311,664,853 (97%)	$319,850,293 (100%)	2%
Yersinia enterocolitica	$19,104,658 (7%)	$7,943,156 (3%)	$251,063,354 (90%)	$278,111,168 (100%)	2%
Total				$15,534,647,106	

*Economic burden is estimated as cost of treatment + productivity loss of working adults + willingness to pay to prevent deaths.

Source: Hoffmann et al., 2012, ERS, Cost of Illness Estimates for Major Foodborne Illnesses in the U.S.

Figure 1

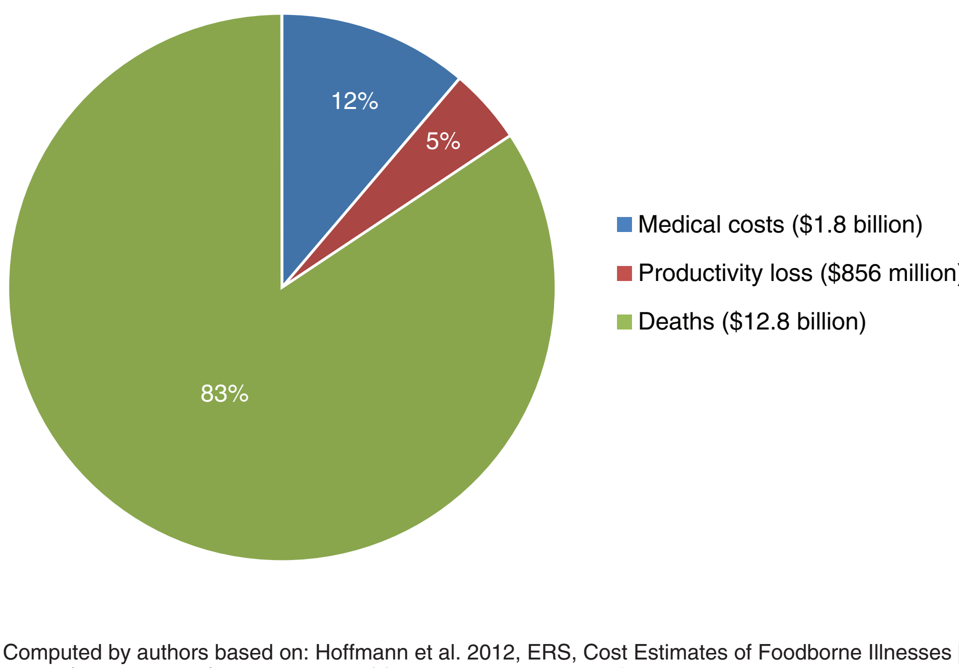
Mean cost of illness for foodborne illnesses acquired in the United States ($ 2013) from 15 leading pathogens



Source: Computed by authors based on: Hoffmann et al. 2012, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Figure 2

Mean cost of illness for foodborne illnesses acquired in the United States ($ 2013) from 15 leading pathogens, by type of cost

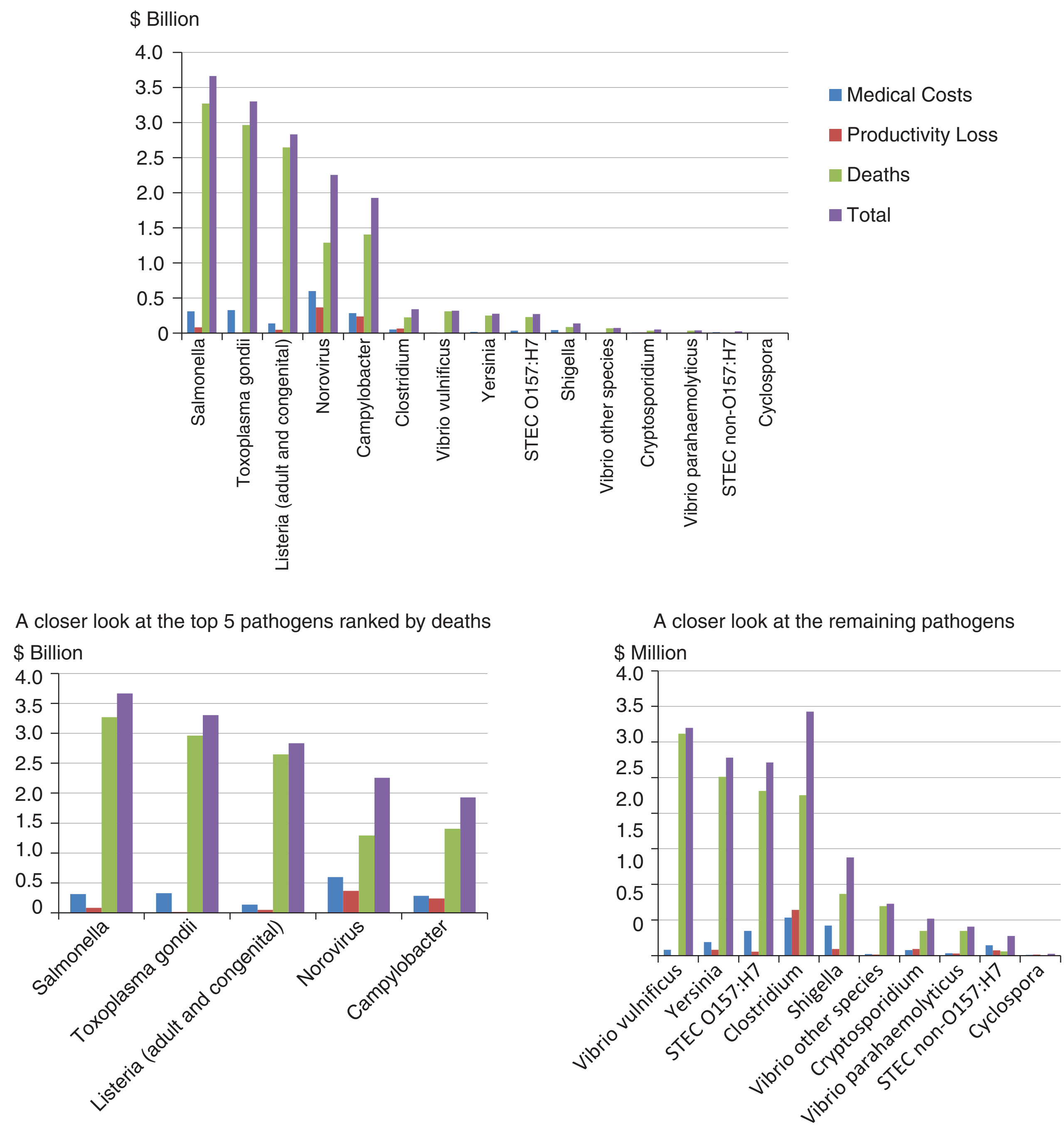


Source: Computed by authors based on: Hoffmann et al. 2012, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Another measure of the importance of foodborne illnesses is the economic burden they impose *per case*. These per-case estimates show the value of having modeling that can integrate outcomes of different severity, like mild diarrhea and chronic kidney disease, into a single metric as compared to basic physical outcome measures like hospitalization and death rates. Economic burden per case is not driven solely by either hospitalization or mortality rates individually or together. The top two pathogens in per-case burden, *Listeria monocytogenes* and *Vibrio vulnificus,* both have high death

Figure 3

Total mean cost of foodborne illnesses in the United States (2013 $)



Source: Computed by authors based on: Hoffmann et al. 2012, ERS, Cost of Illness Estimates for Major Foodborne Illnesses in the U.S. [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

rates, but other factors, including hospitalization rates, matter more than the death rates. Similarly, one would expect *Vibrio* (other non-cholera species) and *Vibrio parahaemolyticus* to rank high because of relatively high death and hospitalization rates. Yet *Toxoplasma gondii* and *Salmonella* (non-typhoidal species) both rank high in terms of economic burden with lower hospitalization and death rates (table 5). The per-case economic burden provides useful insight into the relative value of reducing the incidence of different illnesses. The expected effectiveness and cost of alternative interventions must also be considered.

Examination of uncertainty helps keep estimates in perspective

In almost all complex modeling efforts, there is considerable uncertainty. In this report, the two most important determinants of economic burden are incidence of foodborne illness and the high value people place on reducing risk of death.

It is difficult to estimate the number of new cases of foodborne illness in the U.S. population in a year. Much of infectious disease that could be foodborne, particularly milder illnesses, goes unreported. Furthermore, because foodborne illness symptoms may occur many days or weeks after exposure to a pathogen, it is difficult to determine whether the exposure was foodborne or due to another cause. The CDC's new estimates are the first to quantify uncertainty about foodborne disease incidence (Scallan et al., 2011a/b). The CDC did this by modeling scenarios that represent

Table 5
Economic burden per case of foodborne illnesses in the United States caused by 15 leading foodborne pathogens (2013 $)

	Per-case economic burden	Hospitalization rate (%)	Death rate (%)
Vibrio vulnificus	$3,331,774	91.3	34.8
Listeria monocytogenes	$1,781,549	94.0	15.9
Toxoplasma gondii	$38,114	2.6	0.2
STEC O157	$4,298	46.2	0.5
Vibrio, other non-cholera species	$4,140	37.1	3.7
Salmonella, all non-typhoidal species	$3,568	27.2	0.5
Yersinia enterocolitica	$2,848	34.4	2
Campylobacter, all species	$2,283	17.1	0.1
Vibrio parahaemolyticus	$1,174	22.5	0.9
Shigella, all species	$1,051	20.2	0.1
Cryptosporidium, all species	$899	25.0	0.3
Norovirus	$413	0.03	<0.1
Clostridium perfringens	$355	0.6	<0.1
STEC non-O157	$243	12.8	0.3
Cyclospora cayetanensis	$202	6.5	0

Source: Hoffmann et al. 2012, ERS, Cost of Illness Estimates for Major Foodborne Illnesses in the U.S. [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx, accessed Feb. 7, 2015]; Scallan et al., 2011a.

a 90-percent credible interval—an upper and lower bound—around their mean estimates.[6] So while CDC estimates that annually there are 9.4 million cases of domestically acquired foodborne illnesses for which a pathogen can be identified, they also estimate a 90-percent credible interval of 6.6 million to 12.7 million cases.

CDC's new estimates include credible intervals for each of the 31 pathogens under consideration. We explore the implications of CDC's uncertainty scenarios for economic burden by changing the number of cases to reflect CDC's upper and lower bound estimates of incidence for each pathogen while keeping the same per-case economic burden. For the 15 pathogens included in this report, we estimate that total mean economic burden is $15.5 billion, with a range of $4.8 billion to $36.6 billion (table 6). Table 6 also reports the ratio of pathogens' credible interval to mean economic burden. This ratio provides an indicator of the importance of uncertainty about incidence across pathogens. Pathogens with lower ratios have less uncertainty about economic burden relative to mean economic burden than pathogens with high ratios. Norovirus, *Vibrio vulnificus*, and *Toxoplasma gondii* have ratios of 1 or less, while those for *Shigella*, *Clostridium perfringens*, and *Yersinia enterocolitica* are five times as high or more.

The high value people place on reducing risk of premature death is a major contributor to the magnitude of the economic burden caused by foodborne illnesses: 84 percent of mean economic burden is due to deaths. Our VSL of $8.7 million (2013 dollars) is drawn from a meta-analysis of VSL studies conducted for the U.S. Environmental Protection Agency that also estimated a low value for the VSL of $1.6 million and a high value of $15.7 million (EPA, 2014).[7] We can look at the implications of varying this assumption. Using the mean CDC incidence estimates and the upper and lower bound VSL estimates, the aggregate economic burden of the 15 pathogens examined in this study could be as low as $1.8 billion and as high as $63 billion.

Future updates

The incidence of foodborne illness is likely to change over time, influenced by trends in food processing practices and technology, food sourcing, and demographics (e.g., an aging U.S. population more susceptible to infectious disease). Consumption patterns have changed and will change over time, improving or compromising food safety. New pathogens may emerge, and pathogens currently well controlled may re-emerge as significant problems.

In the next few years, the effects of implementing the Food Safety Modernization Act (FSMA) will become evident. FSMA is the the most significant change in the U.S. Food and Drug Administration's food safety authority since the 1950s. Major provisions of FSMA include onfarm regulation of U.S. produce production; enhanced traceability, requiring all food establishments to have written preventive control plans; new import safety authority; enhanced partnerships with State and local government; and efforts to improve the food safety management capacity of foreign suppliers.

The scientific and economic research on which economic burden estimation is based will also evolve. Research is underway on the chronic consequences of foodborne infections. There is

[6]A credible interval is a concept used in Bayesian statistics that is similar to a confidence interval in more commonly used frequentist statistics.

[7]One way of quantifying uncertainty across a number of studies is to review a body of research, identify studies that meet quality criteria, and conduct statistical analysis on the pooled results or data from those studies. This is called a meta-analysis.

Table 6

Pathogen ranking by total economic burden with sensitivity to assumptions about annual incidence of illnesses, hospitalization, and death*

Pathogen	Mean	Low (5% lower bound)	High (5% upper bound)	Ratio of difference between high and low relative to mean
Salmonella, all non-typhoidal species	$3,666,600,031	$192,932,710	$9,485,969,040	2.53
Toxoplasma gondii	$3,303,984,478	$1,959,565,228	$4,931,033,852	0.90
Listeria monocytogenes	$2,834,444,202	$227,549,601	$7,639,074,438	2.61
Norovirus	$ 2,255,827,318	$1,283,912,531	$3,546,351,551	1.00
Campylobacter, all species	$1,928,787,166	$903,992,237	$4,643,378,441	1.94
Clostridium perfringens	$342,668,498	$22,343,043	$1,735,180,964	5.00
Vibrio vulnificus	$319,850,293	$169,164,103	$505,687,764	1.05
Yersinia enterocolitica	$278,111,168	$3,920,678	$1,551,697,588	5.57
STEC O157	$271,418,690	$25,452,077	$1,191,978,238	4.30
Shigella, all species	$137,965,962	$9,996,590	$714,564,650	5.11
Vibrio, other non-cholera species	$72,827,353	$28,173,164	$169,847,090	1.95
Cryptosporidium, all species	$51,813,652	$3,930,816	$212,092,871	4.02
Vibrio parahaemolyticus	$40,682,312	$3,147,956	$157,326,138	3.79
STEC non-O157	$27,364,561	$1,641,801	$88,091,681	3.16
Cyclospora cayetanensis	$2,301,423	$24,503	$9,326,330	4.04
Total for 15 pathogens above	$15.5 billion	$4.8 billion	$36.6 billion	

*This table examines uncertainty in USDA/ERS estimates of the economic burden of foodborne illness acquired in the United States by varying annual incidence of illnesses, hospitalizations, and deaths. Annual incidence estimates used are the mean and 90% credible interval estimates of cases, hospitalizations, and deaths from Scallan et al. (2011). Foodborne illness acquired in the United States—major pathogens. *Emerging Infectious Diseases* [serial on the Internet]. http://dx.doi.org/10.3201/eid1701.P11101.

Source: Hoffmann et al. 2012, ERS, Cost of Illness Estimates for Major Foodborne Illnesses in the U.S. [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

continuing interest in improving estimates of foodborne illness incidence, particularly in reducing uncertainty about incidence estimates. New economic research on willingness to pay to reduce risk of neurological damage in children may provide a truer estimate of the economic burden of some congenital conditions. QALY measures are being used more broadly in public health, generating increased interest in finding ways to value them monetarily that are consistent with economic theory.

USDA's Economic Research Service plans on updating these estimates of the economic burden of foodborne illnesses every 5 years. These revisions will involve a review of emerging literature on the incidence and impacts of foodborne illnesses as well as changes in economics data and research. We will also consider whether more pathogens and possibly some nonpathogenic hazards can be included in future estimates.

Economic Burden Estimates by Pathogen

Introduction

The remainder of this report consists of summaries for 15 leading foodborne pathogens in the United States. Each contains:

- recent foodborne illness incidence estimates for the pathogen;
- a description of illness (both acute and, where applicable, chronic) symptoms, durations, and likely health outcomes used in in economic burden modeling;
- summary estimates of the economic burden of the pathogen and its place relative to other pathogens in this analysis; and
- the implications of modeling uncertainty for estimates of the pathogen's economic burden.

The summaries include disease-outcome trees for each pathogen and a pie chart showing the share of the pathogen's total economic burden that is due to different possible health outcomes resulting from a foodborne infection by the pathogen.

Disease-outcome trees show the outcomes of infections. These vary from mild illnesses that require no medical care to severe illnesses that result in death. The starting point for each disease-outcome tree is the number of new cases of illness each year. From this starting point, the tree branches out to show the percent of new cases each year that result in different health outcomes. The end point is either recovery, chronic illness, or death. Our disease-outcome trees include the mean incidence and economic burden of each health outcome together with its 90-percent credible interval. Detailed descriptions of the information underlying the disease-outcome trees can be found in the online supplemental appendixes to Batz et al. (2014).

As an example, the disease-outcome tree for *Campylobacter* spp. (fig. 4) shows that there are 845,000 foodborne illnesses caused by the pathogen each year and that these cause $1.9 billion in economic burden. The 90-percent credible interval for total *Campylobacter* incidence is 337,000 to 1.6 million cases with a credible interval for economic burden of $903 million to $4.6 billion. Approximately 94 percent of cases become ill but never seek a doctor's care, 5 percent do seek a doctor's care but no further medical assistance, and 1 percent are hospitalized. For each of these outcomes, the tree shows the number of cases, the associated economic burden, the range of possible cases due to uncertainty, and the range of associated economic burden. So, for example, 5 percent of the people who become ill (or about 45,000 people) seek a doctor's care with an economic burden of $28 million. This could range from 18,000 to 87,000 people, with an associated economic burden of $11 million to $54 million. Ninety-nine percent of hospitalized cases recover and 1 percent die.

For some pathogens, like *Campylobacter*, infections can result in chronic consequences. In figure 4, the bracket at the left hand side indicates that the chronic condition, Guillain Barré syndrome, can occur following illnesses of any severity. The summaries also include a pie chart showing the mean percentage of cases that experience different health outcomes and their associated economic burden. We include citations and Web links to CDC and Food and Drug Administration (FDA) educational resources to make it easier for users to access these resources.

In some disease-outcome trees—for example, for adult cases of *Listeria monocytogenes* infections (fig. 17a)—there are different types or severities of hospitalization. In our modeling, death is always preceded by hospitalization.

The CDC National Center for Emerging and Zoonotic Infectious Disease maintains a helpful website with general information on the pathogens included in this report (CDC 2014). The FDA's Bad Bug Book is also a useful source of pathogen-specific information on foodborne illnesses (FDA, 2012). Readers may also find short consumer-oriented factsheets from FDA and USDA's Food Safety and Inspection Service to be helpful: FDA, "Foodborne Illness-Causing Organisms in the U.S.: What You Need to Know," at http://www.fda.gov/downloads/Food/FoodborneIllnessContaminants/UCM187482.pdf; FSIS, "Foodborne Illnesses: What You Need to Know," available at http://www.fda.gov/food/resourcesforyou/consumers/ucm103263.htm. All of these were used as sources of general disease information for these summaries.

Campylobacter spp. (all species)

Campylobacter spp. is a common cause of all diarrheal illness acquired in the United States, and one of the more common causes of foodborne illness (CDC, 2014). About 80 percent of all *Campylobacter* cases acquired in the United States in a typical year are foodborne (Scallan et al., 2011a). *Campylobacter* causes about 9 percent of the cases of foodborne illnesses for which the CDC can identify a pathogen cause (table 3). Usually, *Campylobacter* infection results in mild to moderate illness that can be treated at home, but roughly 1 percent of cases require hospitalization. *Campylobacter* ranks third as a known cause of hospitalizations resulting from foodborne infections, causing about 15 percent. While only 0.1 percent of infections with *Campylobacter* result in death, the pathogen accounts for almost 6 percent of deaths from U.S. foodborne illnesses where the pathogen cause can be identified (table 3).

It generally takes 2 to 5 days after exposure before people experience symptoms from *Campylobacter* infections (FDA, 2012). People with mild *Campylobacter* infections will experience diarrhea, cramping, fever, and abdominal pain. They may also experience nausea and vomiting. With mild illnesses, symptoms generally resolve in less than a week without professional medical attention. More severe illness may result in bloody diarrhea and can last 1-2 weeks. In our estimates, we assume that mild cases last an average of 2 days and that cases requiring medical attention—but not hospitalization—resolve in an average of 5 days (Batz et al., 2014). More serious cases may require hospital stays, which we assume last 6 days followed by an average of 3 days recuperation at home.

In rare cases, *Campylobacter* infections have more long-term health consequences. Less than 0.25 percent of people who are infected with *Campylobacter*, about 2,000 people a year, develop a rare neurological disease called Guillain-Barré syndrome (GBS) that typically begins several weeks after the diarrhea.[8] GBS results in paralysis that can affect any part of the body. It can be life threatening when it affects the heart and lungs. While the paralysis is typically temporary, it generally requires intensive medical treatment and rehabilitation. Some people experience ongoing weakness. The CDC reports that as many as 40 percent of GBS cases in the United States may be triggered by *Campylobacter* infections.

Campylobacter ranks fifth in terms of economic burden among the 15 pathogens included in this report, and eighth on a per-case basis (tables 4 and 5). It imposes an estimated $1.9 billion in economic burden in a typical year (table 4). Over half of this, 56 percent or $1.1 billion, is due to Guillain-Barré syndrome (fig. 5). This means that less than 0.25 percent of the cases of infections from foodborne *Campylobacter* cause over 50 percent of the economic burden. Another 34 percent of the economic burden, or $658 million, is due to deaths resulting from acute illnesses. Only 10 percent of the economic burden of infections from *Campylobacter*, $202 million, is due to non-hospitalized and hospitalized acute illnesses (fig. 5).

The CDC estimates *Campylobacter* infections at 845,024 cases in a typical year. Based on the 90-percent credible interval around the mean estimate, *Campylobacter* infections could be as low as 337,031 cases and as high as 1,661,083 (Scallan et al., 2011a). Economic burden could range from $903 million to $4.6 billion per year (table 6).

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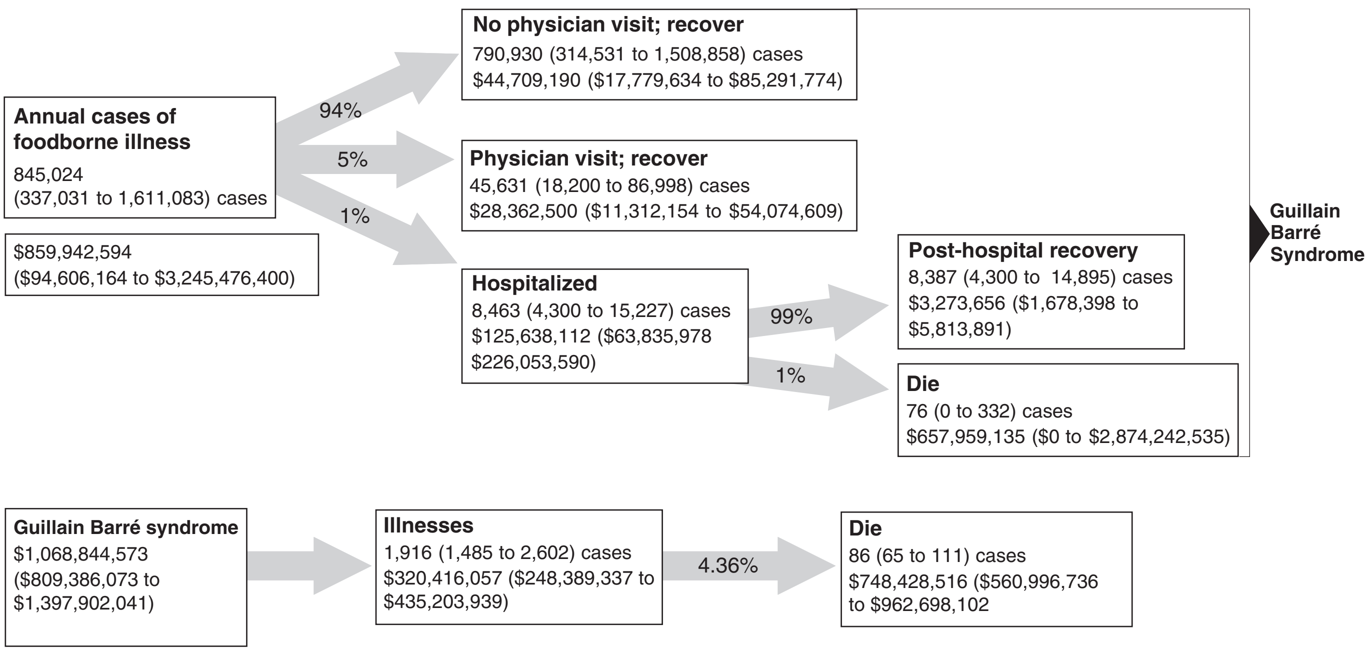
[8]Some people develop arthritis from *Campylobacter* infections. Data were not adequate to include post-infection arthritis in our analysis, but this will likely be added in future updates (Batz et al., 2014).

Figure 4

Disease-outcome tree for annual foodborne illnesses caused by *Campylobacter spp.* (all species) acquired in the United States (2013 dollars)

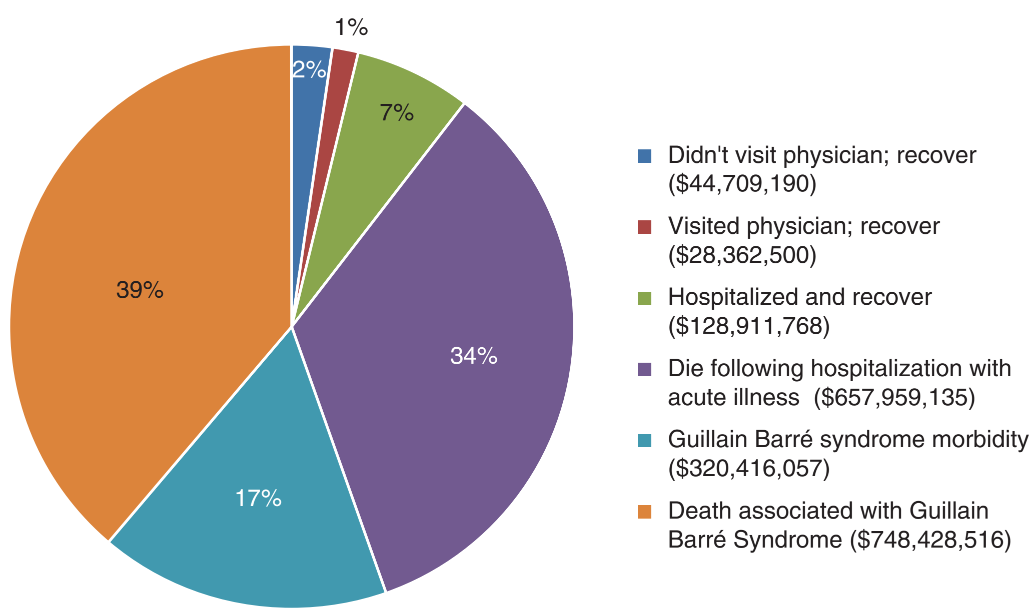
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 5

Mean economic burden of annual foodborne illnesses caused by *Campylobacter spp.* (all species) acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al. 2012, USDA ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Clostridium perfringens

Each year, about 966,000 people become sick from food contaminated with *C. perfringens.* The pathogen is one of the most common causes of foodborne illness, accounting for about 10 percent of U.S. cases for which a pathogen can be identified (table 3). While *C. perfringens* causes more cases of foodborne illness than *Campylobacter,* it causes more mild illness and results in a much lower rate of hospitalization and death, about 440 hospitalizations and 25 deaths each year. So while *C. perfringens* ranks third in terms of number of illnesses caused, it ranks eighth in number of deaths caused by food-borne illness in the United States for which a pathogen cause can be identified (table 3).

In most of the population, *C. perfringens* is a mild illness involving watery diarrhea and mild abdominal cramps. Onset of symptoms is typically within 8 to 12 hours of eating contaminated food. For most people, the illness lasts less than 24 hours. In the very young, the elderly, and those whose immune systems are compromised, complications such as dehydration can result in more serious illness and in rare cases, death. We assume that the 90 percent of people with foodborne infections from *C. perfringens* who do not see a physician recover within an average of 2 days (fig. 6). The 10 percent of infected people who do seek a physician's care, but are not hospitalized, are sick for an average of 4 days (Batz et al., 2014). Only 0.05 percent of those infected with foodborne *C. perfringens* are hospitalized in a typical year (Scallan et al., 2011). Of these, 94 percent recover after a hospitalization of 3 days, followed by 6 days of post-hospitalization recovery. Roughly 6 percent of those hospitalized die.

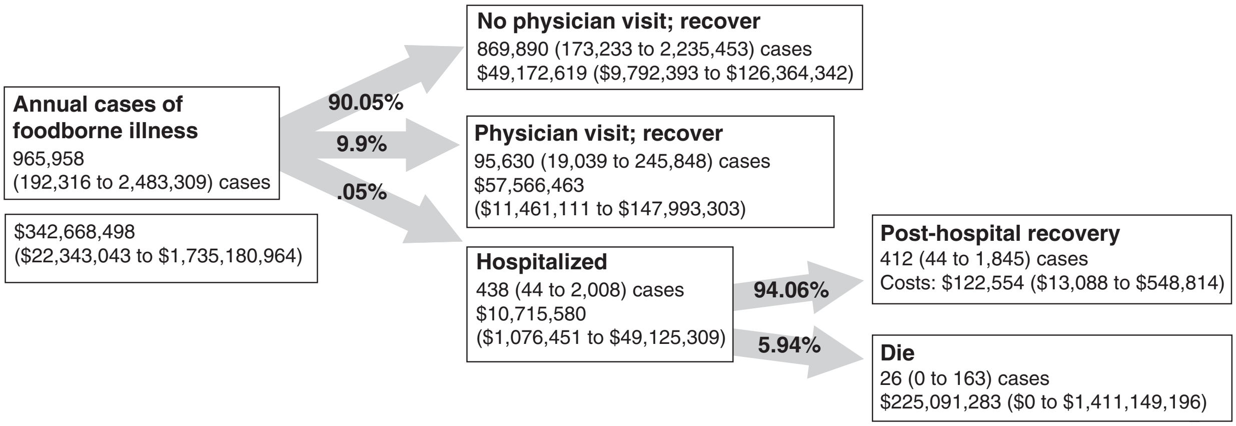
Clostridium perfringens ranks 6th among the 15 pathogens included in this report in terms of economic burden of foodborne illnesses and 13th on a per-case basis (tables 4 and 5). It imposes an estimated $343 million in economic burden in a typical year. Nearly two-thirds of this economic burden is due to the roughly 26 deaths that occur each year (fig. 7). Relatively mild cases that do not require hospitalization account for almost a third of the economic burden imposed by *C. perfringens* in a typical year.

As with the other foodborne pathogens in this report, these estimates are uncertain. *C. perfringens* incidence could be as low as 192,000 and as high as 2.5 million cases in a typical year (Scallan et al., 2011a). Economic burden could range from $22 million to $1.7 billion per year (table 6).

Figure 6

Disease-outcome tree for annual foodborne illnesses caused by *Clostridium perfringens* acquired in the United States (2013 dollars)

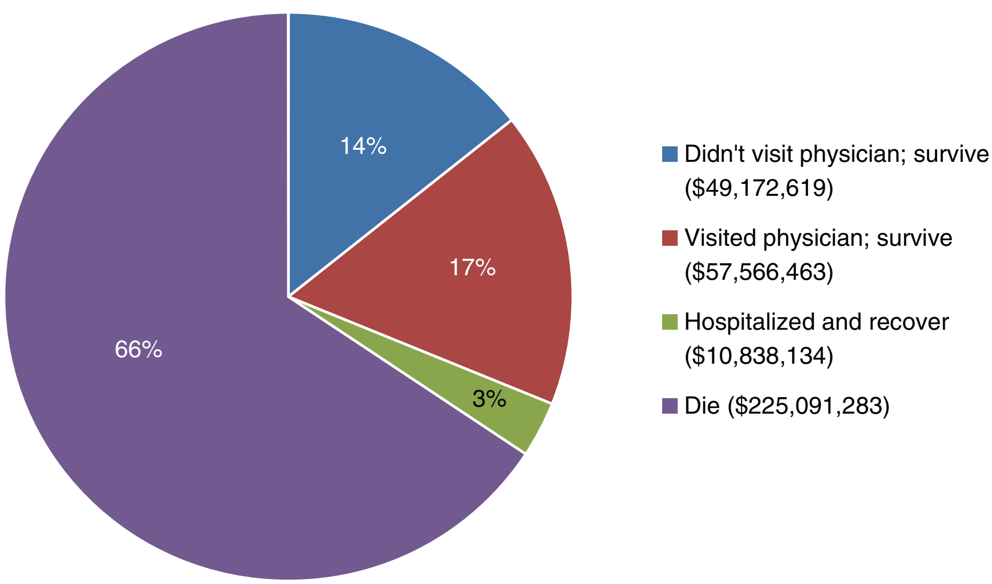
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al. 2014.

Figure 7

Mean economic burden of annual foodborne illnesses caused by *Clostridium perfringens* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al. 2012, USDA ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Cryptosporidium spp. (all species)

Cryptosporidium spp. is one of the most common causes of *waterborne* illness in the United States. Typically people are exposed to this parasite through water recreation or drinking contaminated water. Studies using blood tests indicate that 80 percent of the U.S. population has been infected with *Cryptosporidium* at some point in their lives (FDA, 2013). While water is the most common exposure route for this parasite, people can also be exposed to *Cryptosporidium* on produce irrigated with contaminated water or from contamination by food handlers who are infected. *Cryptosporidium* causes about 58,000 cases of *foodborne* illness in a typical year, resulting in about 210 hospitalizations and 4 deaths. It causes less than 1 percent of the illnesses, hospitalizations, and deaths from foodborne infection that can be attributed to a specific pathogen cause (table 3).

In most of the population, infections with *Cryptosporidium* result in relatively mild illness. Symptoms generally appear 7 to 10 days after exposure. About 88 percent of people who are infected recover without seeking medical care (fig. 8). In our economic burden estimates, we model these mild illnesses as lasting 2 days on average (Batz et al., 2014). *Cryptosporidium* can produce very profuse watery diarrhea, up to 3 to 6 liters per day. Dehydration can become a major concern, particularly for pregnant women, young children, and those who have compromised immune systems. Nearly 12 percent of those infected with *Cryptosporidium* are ill enough to see a physician, but are not hospitalized. We model these cases as having 4 days of illness (Batz et al., 2014). Hospitalization is rarely required; about 0.4 percent of all cases are hospitalized for an average of 3 days, followed by 6 days of post-hospitalization recovery.

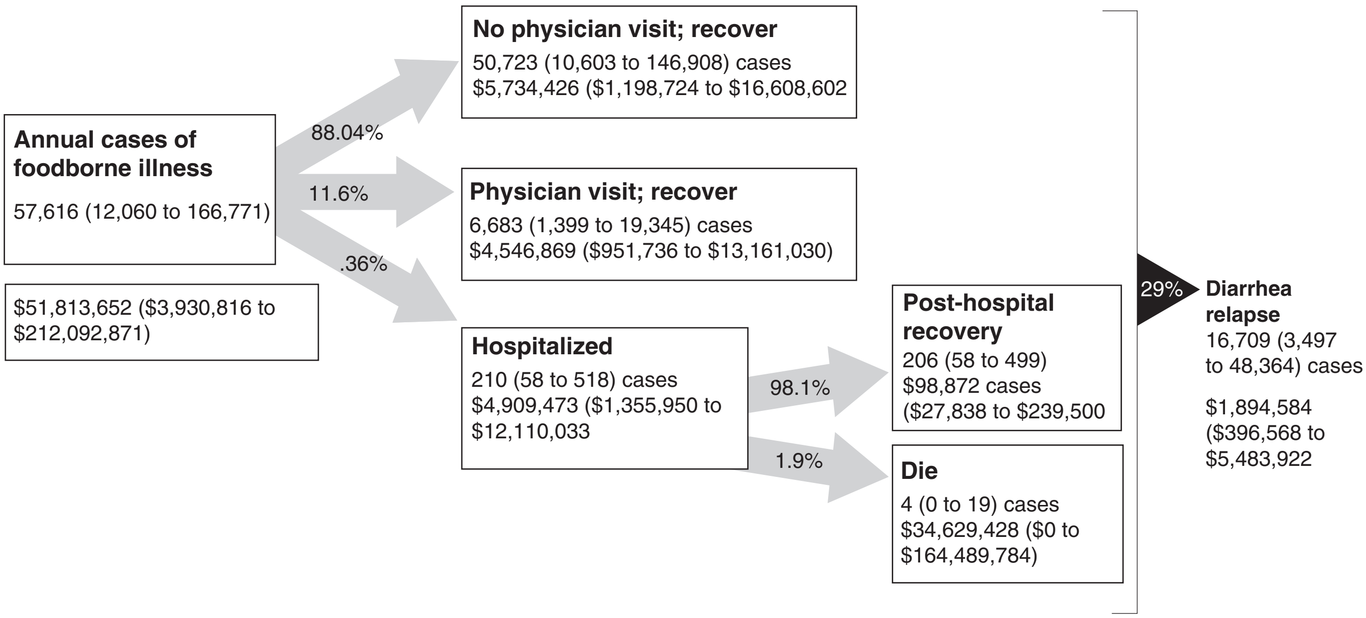
Cryptosporidum ranks 12th among the 15 pathogens included in this report in terms of economic burden and 11th on a per-case basis (tables 4 and 5). It imposes an estimated $52 million in economic burden in a typical year (table 4). Two-thirds of this economic burden is due to the four deaths that occur each year (fig. 9). Non-hospitalized cases account for 20 percent of this burden in a typical year. Hospitalized cases account for only 3 percent of the economic burden of foodborne *Cryptosporidium*, or $5 million.

The CDC estimates the incidence of foodborne *Cryptosporidium* at 57,600 cases in a typical year (fig. 8). As with the other foodborne pathogens, there is considerable uncertainty about this estimate. *Cryptosporidum* incidence could be as low as 12,000 and as high as 167,000 (Scallan et al., 2011a). Economic burden could range from $3.9 million to $212 million per year.

Figure 8

Disease-outcome tree for annual foodborne illnesses caused by *Cryptosporidium* spp. acquired in the United States (2013 dollars)

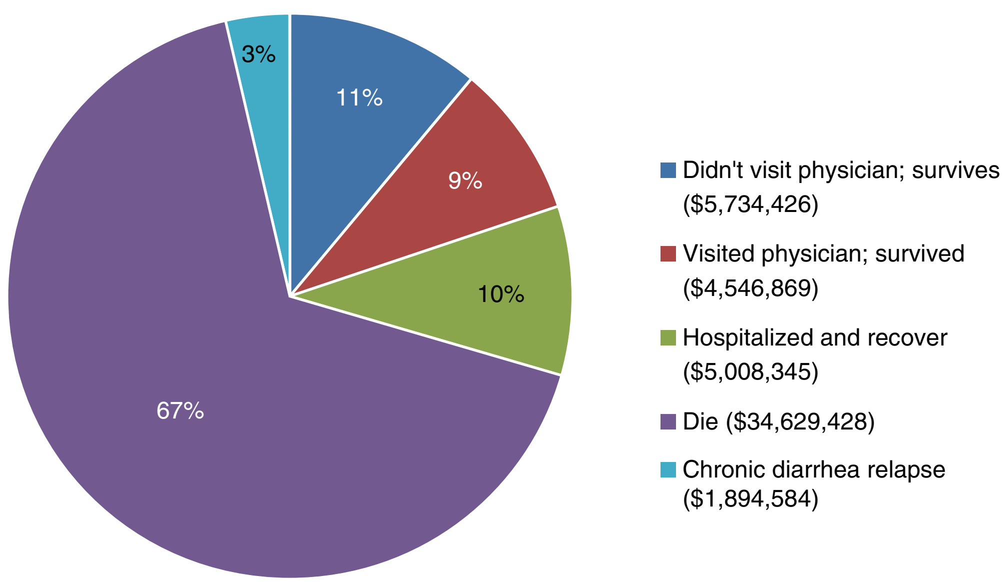
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al. 2014.

Figure 9

Mean economic burden of annual foodborne illnesses caused by *Cryptosporidium spp.* (all species) acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al. 2012, USDA ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Cyclospora cayetanensis

Cyclospora cayetanensis is a single-celled parasite found mainly in tropical regions. In the United States, outbreaks of foodborne infections with *Cyclospora cayetanensis* have been linked to consumption of imported fresh produce. *Cyclospora cayetanensis* causes about 11,000 cases of foodborne illness in a typical year, 11 hospitalizations, and no deaths (table 3). Together, 16 of the 31 pathogens for which CDC can estimate pathogen-specific foodborne illness incidence cause fewer foodborne illnesses each year than Cyclospora (table 3).

Symptoms of foodborne *Cyclospora cayetanensis* infection typically do not appear for about a week after eating contaminated food. Symptoms include watery diarrhea (sometimes in explosive bowel movements), loss of appetite, abdominal cramps, nausea, bloating, and fatigue. Vomiting, fever, and other flu-like symptoms may occur. Over 88 percent of people infected with foodborne *Cyclospora cayetanensis* recover without seeking medical care (fig. 10). We model these cases as lasting an average of 4 days (Batz et al., 2014). About 12 percent of cases do see a doctor but are not hospitalized. We model these cases as lasting 6 days. About 0.1 percent of foodborne *Cyclospora cayetanensis* infections are hospitalized for an average of 6 days, followed by 19 days of post-hospitalization recovery. *Cyclospora cayetanensis* rarely causes death in the United States and is not generally reported to have long-term consequences.

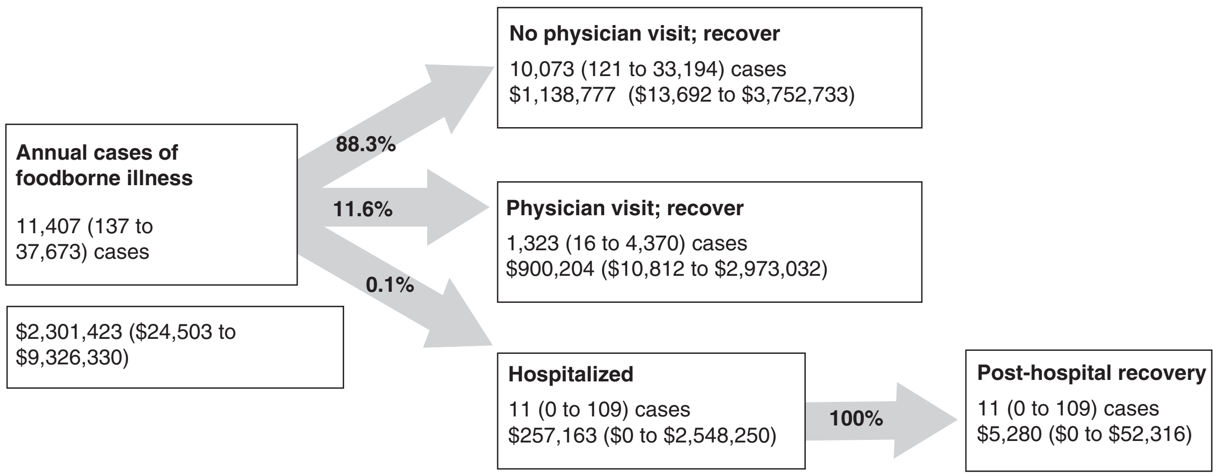
Cyclospora cayetanensis ranks last among the 15 pathogens included in this report in terms of total and per-case economic burden, due both to its relatively low incidence and mortality rates. Even so, it imposes an average of $2.3 million in economic burden in a typical year (table 4). Nearly half of this burden ($1.1 million) is due to the 10,000 cases where a doctor's care is not sought (fig. 11). Another 39 percent of burden ($900,000) is due to the 1,300 cases that do seek a physician but are not hospitalized. Hospitalized cases account for 11 percent of the burden ($260,000) (fig. 11).

As with the other foodborne pathogens in this report, there is considerable uncertainty about these estimates. CDC estimates that the incidence of foodborne *Cyclospora cayetanensis* infections in the United States could be as low as 140 cases and as high as 38,000 in a typical year (Scallan et al., 2011a). Economic burden could range from $25,000 to $9.3 million per year (table 6).

Figure 10

Disease-outcome tree for annual foodborne illnesses caused by *Cyclospora cayetanensis* acquired in the United states (2013 dollars)

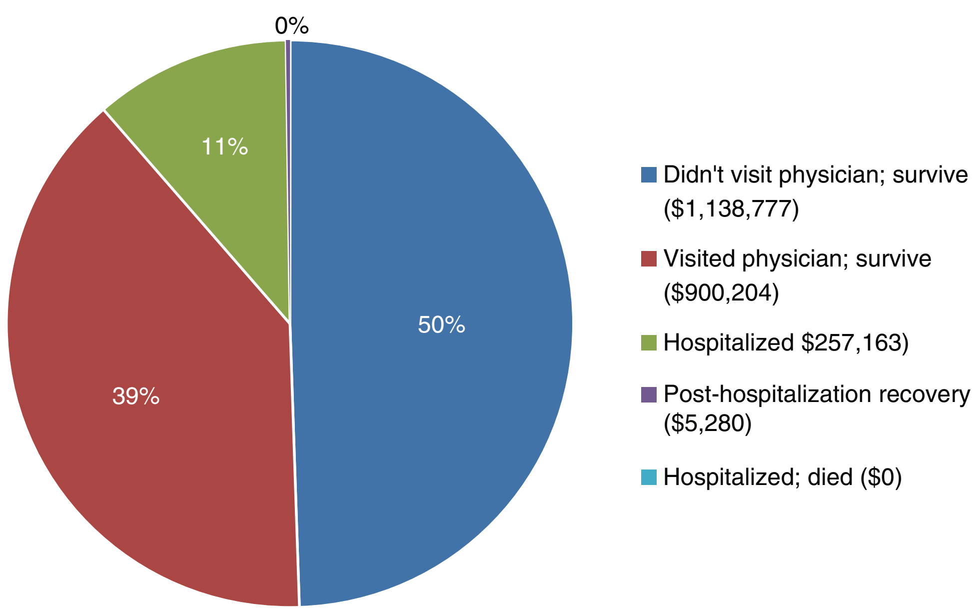
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 11

Mean economic burden of annual foodborne illnesses caused by *Cyclospora cayetanensis* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Listeria monocytogenes

Food is the primary route of human exposure to *Listeria monocytogenes. Listeria* survives on many types of surfaces and can grow under refrigeration. It is a particular concern for older adults, pregnant women, newborns, and adults with compromised immune systems. Even though just 1,600 people, on average, are sickened by foodborne *Listeria*, it ranks 3rd among causes of foodborne illness-associated deaths in the United States, causing nearly 19 percent of such deaths (255 in a typical year) (table 3). *Listeria* causes about 280 cases of illness in newborns in a typical year, resulting in 60 deaths and stillbirths. Infants can be infected before birth, and this infection can cause serious disability in newborns. About 35 infants are disabled as a result of infection from *Listeria* each year (fig. 12b). These infections typically result from their mothers' foodborne exposure to the pathogen during pregnancy.

Symptoms of *Listeria monocytogenes* infections are typically flu-like, including fever, chills, and muscle ache, sometimes but not always accompanied by diarrhea and/or stomach upset. About 10 percent of noncongenital cases of foodborne *Listeria* infections resolve without medical attention (fig. 12a), lasting an average of 3 days (Batz et al., 2014). Ninety percent of cases require hospitalization. About 3 percent of hospitalized cases are moderate, with an average stay of 7 days and a 21-day post-hospitalization recovery (Batz et al., 2014). Eighty percent of adult hospitalizations require ICU (intensive care unit) care. These cases typically have sepsis and/or meningitis and are more common in the elderly and those with compromised immune systems. Over one in four adults who require ICU care for *Listeria* infection die (Batz et al., 2014). Adults who survive generally recover fully without long-term health impacts.

Seventeen percent of those hospitalized with foodborne *Listeria* infections acquired in the United States are pregnant women (fig. 12a). While pregnant women generally recover without further complications to themselves, the infection can be passed on through the placenta to the fetus. Each year, an average of 282 cases of congenital illnesses result from women contracting foodborne *Listeria* infections during pregnancy (fig. 12b) (Batz et al., 2014). In newborns, *Listeria* infections can cause spinal meningitis and sepsis. Two-thirds of infants born with *Listeria* infections recover fully, but require an average of 21 days of hospitalization after birth. Twenty-one percent of these congenitally acquired infections result in death (86 percent of these are stillbirths or miscarriages and 14 percent are neonatal deaths). Twelve percent of congenital infections result in permanent disabilities of varying degrees of severity (Batz et al., 2014).

Listeria ranks 3rd among the 15 pathogens included in this report in terms of total economic burden(tables 5 and 6). It imposes an estimated $2.8 billion in economic burden in a typical year. Almost all of this, $2.1 billion, is due to deaths. This burden results from only 1,600 illnesses, making *Listeria* the second most costly of foodborne diseases per case ($1.8 million) (table 5).

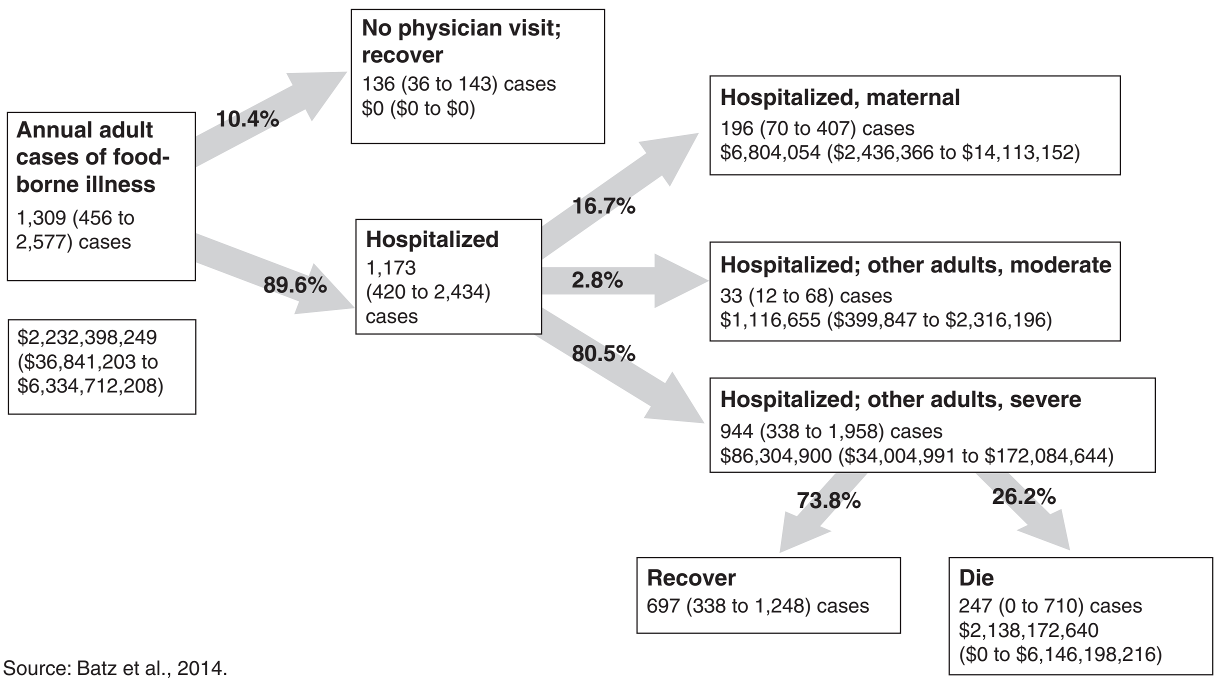
Foodborne *Listeria* infections in newborns and prenatal infections impose $600 million in economic burden annually (22 percent of total foodborne *Listeria* economic burden) (fig. 13). $510 million of the burden is due to neonatal deaths and stillbirths. Another $67 million (11 percent of congenital listeriosis burden) is due to disabilities resulting from the infections.

While the CDC estimates an annual average of 1,600 cases of foodborne *Listeria* illnesses, it could be as low as 560 and as high as 3,200 cases (Scallan et al., 2011a). Uncertainty about incidence implies that the true economic burden of foodborne *Listeria monocytogenes* infections could range from $228 million to $7.6 billion per year (table 6).

Figure 12a

Disease-outcome tree for annual foodborne illnesses in adults caused by *Listeria monocytogenes* acquired in the United States (2013 dollars)

Mean cases and economic burden estimates (5th to 95th % credible interval)

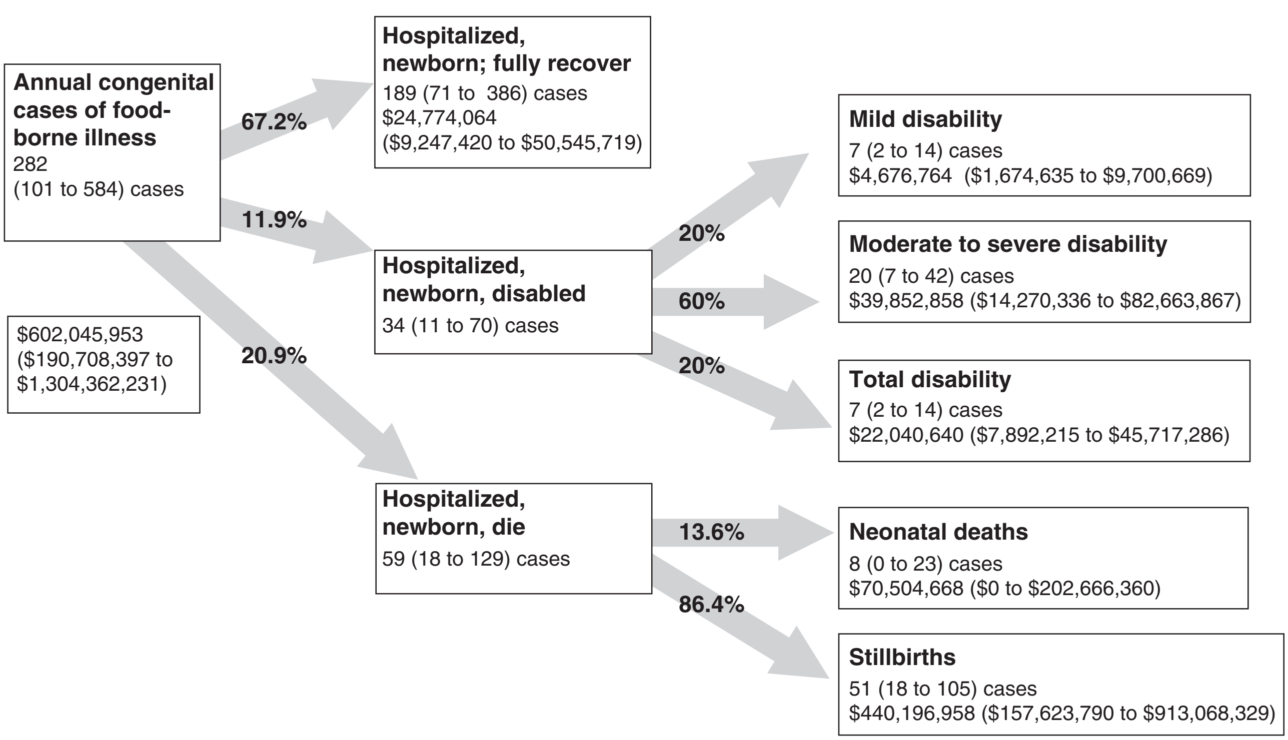


Source: Batz et al., 2014.

Figure 12b

Disease-outcome tree for annual congenital foodborne illnesses caused by *Listeria monocytogenes* acquired in the Unied States (2013 dollars)

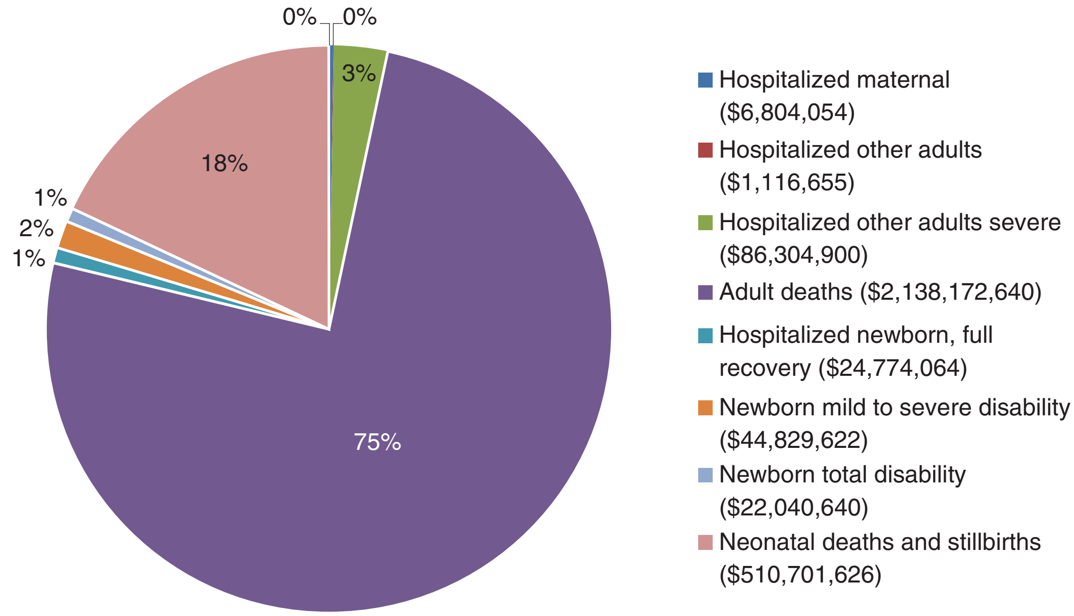
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 13

Mean economic burden of annual foodborne illnesses caused by *Listeria monocytogenes* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Norovirus

Norvirus causes 58 percent of foodborne illnesses in the United States that can be linked to a specific pathogen, 5.5 million cases in a typical year (table 3). It is highly contagious and transmittable via a wide variety of exposure routes, including contact with an infected person, contaminated food or water, or contaminated surfaces. Norovirus generally causes mild illness and, as a result, has the lowest hospitalization rate (0.3 percent of cases) among major foodborne pathogens. It also has a low death rate, less than 0.1 percent of cases (Scallan et al., 2011). Yet, because Norovirus causes almost five times as many cases as the next most important cause of U.S. foodborne illness, *Salmonella*, it is also a major cause of hospitalization and death from foodborne illness. Norovirus causes over 26 percent of hospitalizations and 11 percent of deaths from foodborne illnesses acquired in the United States for which a specific pathogen cause can be identified (table 3).

People often refer to Norovirus as "the stomach flu" even though it is not a flu. Norovirus is not an influenza virus, but it does cause flu-like symptoms including fever, body aches, and headaches. Projectile vomiting is often the first sign of the illness. It also causes nausea, watery diarrhea, and stomach pain. Most cases of infection with Norovirus are mild and short-lived. Ninety percent of cases recover without seeking medical care (fig. 14). These cases are modeled as lasting 2 days (Batz et al., 2014). In about 10 percent of cases, a physician's care is sought but no hospitalization is required. These cases are typically more severe, often due to dehydration, and are modeled as lasting 4 days (Batz et al., 2014). Less than 0.3 percent of cases require hospitalization. Dehydration is the most common complication, particularly in the elderly, young children, and those with underlying medical conditions. On average, these hospitalizations last 3 days and require another 6 days of post-hospitalization recovery (Batz et al., 2014).

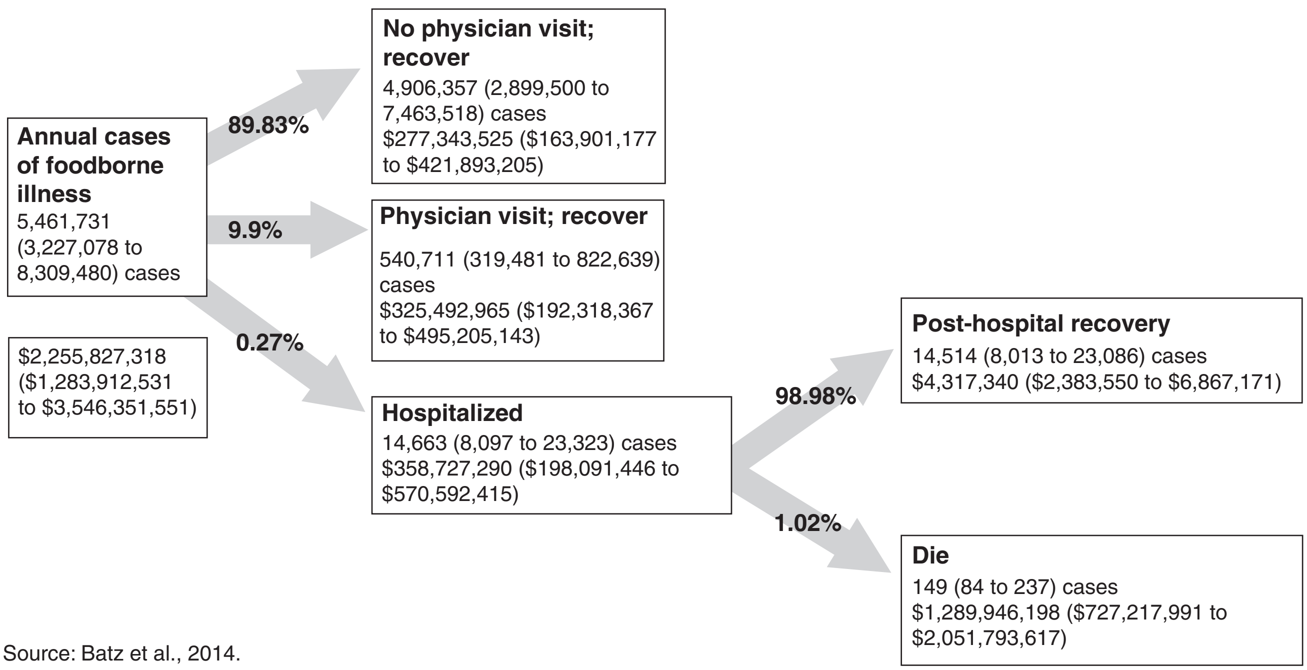
Norovirus ranks 4th among the 15 pathogens included in this report in terms of total economic burden among the 15 pathogens in this report, 12th on a per-case basis (tables 5 and 6). It imposes an estimated $2.3 billion in economic burden in a typical year. Fifty-seven percent of this burden, $1.3 billion, is due to deaths; 27 percent, $602 million, is due to non-hospitalized cases; and 16 percent, $363 million, is due to hospitalizations (fig. 15).

While CDC estimates the incidence of foodborne Norovirus infections at 5.5 million cases in a typical year, it could be as low as 3.2 million cases and as high as 8.3 million cases (Scallan et al., 2011a). Economic burden could range from $1.3 billion to $3.5 billion per year (table 6).

Figure 14

Disease-outcome tree for annual foodborne illnesses caused by Norovirus acquired in the United States (2013 dollars)

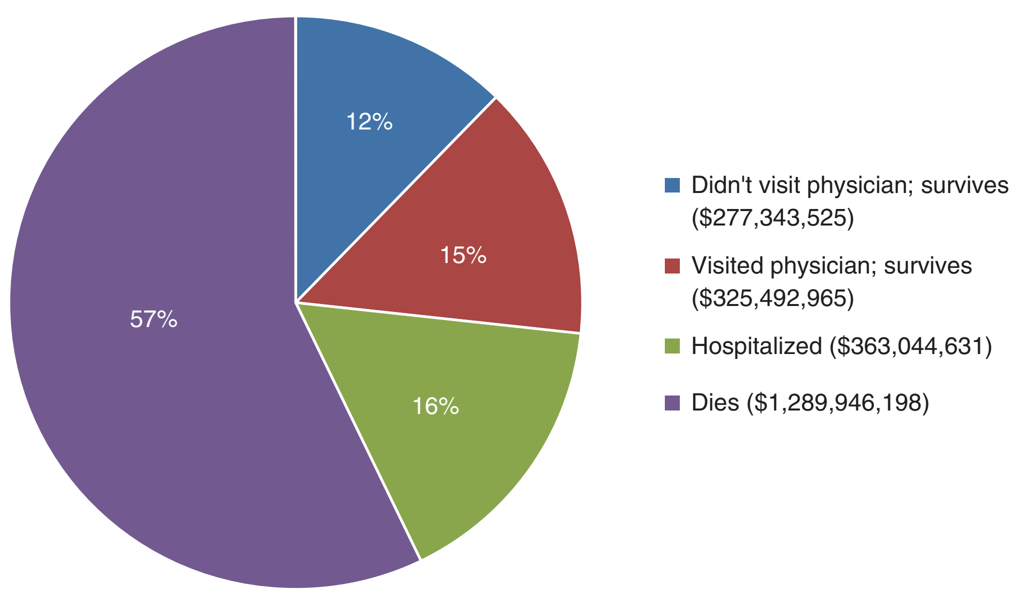
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 15

Mean economic burden of annual foodborne illnesses caused by Norovirus acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al. 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Salmonella (non-typhoidal species)

Each year, roughly a million people in the United States become ill from a non-typhoidal foodborne *Salmonella* infection (11 percent of foodborne illnesses) (table 3). Non-typhoidal *Salmonella* species are the leading cause of hospitalizations and deaths caused by foodborne illnesses that can be linked to a specific pathogen, causing 35 percent of hospitalizations (19,000 cases) and 28 percent of deaths (378 deaths) (table 3). *Salmonella* lives in the intestines of most mammals (including humans), birds, and reptiles. People are typically exposed to *Salmonella* through food, water, or surfaces contaminated with feces or by handling reptiles or birds.

Symptoms of non-typhoidal foodborne *Salmonella* infections generally appear from 6 hours to 3 days after exposure. For most healthy people, *Salmonella* causes mild diarrhea, vomiting, fever, and headache. Over 90 percent of foodborne cases recover without seeking medical care (fig. 16). We model these cases as lasting about 2 days on average (Batz et al., 2014). Seven percent of those ill with a foodborne *Salmonella* infection see a physician but are not hospitalized. These cases are modeled as lasting 5 days.

About 2 percent of cases are severe enough to require hospitalization. Usually these cases involve bloody diarrhea and/or dehydration requiring intravenous fluids. Ninety-eight percent of those hospitalized recover; 2 percent die (fig. 16). On average, hospitalizations last 6 days followed by 3 days of post-hospitalization recovery. A small number of people infected with *Salmonella* may also develop reactive arthritis, with symptoms appearing about a month after acute symptoms appear. We did not find enough evidence to quantify the extent of this outcome.

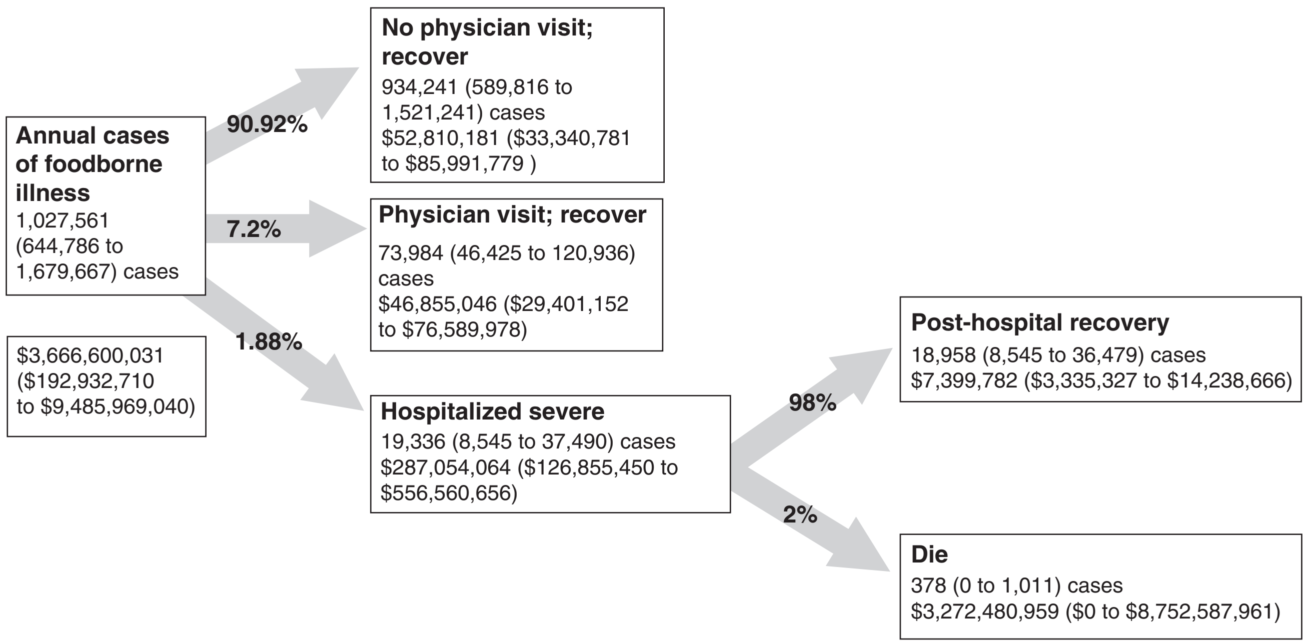
Salmonella ranks 1st among the 15 pathogens included in this report in terms of economic burden among the 15 pathogens included in this study and 6th on a per-case basis (tables 5 and 6). It imposes an estimated $3.7 billion in economic burden in a typical year. Almost 90 percent of this burden, $3.3 billion, is due to deaths; 8 percent, $294 million, is due to hospitalization; and the remaining 2 percent is due to non-hospitalized cases (fig. 17).

While CDC estimates the incidence of foodborne *Salmonella* infections at a little over 1 million cases in a typical year, it could be as low as 645,000 cases and as high as 1.7 million cases (Scallan et al., 2011a). Economic burden could range from $193 million to $9.5 billion per year (table 6).

Figure 16

Disease-outcome tree for annual foodborne illnesses caused by *Salmonella* (nontyphoidal species) acquired in the United States (2013 dollars)

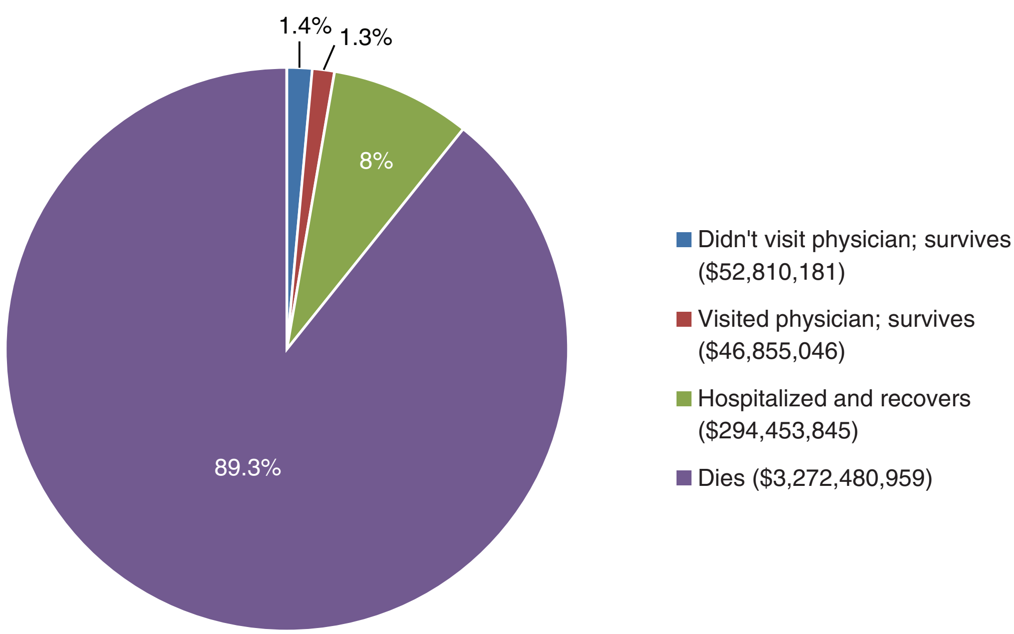
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 17

Mean economic burden of annual foodborne illnesses caused by *Salmonella* (non-typhoidal species) acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Shigella spp. (all species)

Each year, *Shigella* spp. causes about 131,000 foodborne illnesses, 1,500 hospitalizations, and 10 deaths in the United States. This represents about 1.4 percent of cases, 2.6 percent of hospitalizations, and less than 1 percent of deaths from foodborne illnesses that can be linked to a specific pathogen (table 3). As with most foodborne pathogens, *Shigella* is transmitted by feces. Food can become contaminated with *Shigella* when infected people do not properly wash their hands and handle food, or when crops are irrigated or rinsed with contaminated water.

Symptoms of infection with foodborne *Shigella* typically appear 8 hours to 2 days after eating contaminated food. In the United States, most cases are relatively mild; 92 percent of those infected recover within an average of 2 days without seeing a doctor. Symptoms include diarrhea, abdominal cramping and pain, and headache. Another 7 percent of those with foodborne *Shigella* infections see a doctor but do not require hospitalization (fig. 18). These cases are typically more severe and last an average of 5 days. About 1 percent of cases require hospitalization, which is more likely with severe dehydration or bloody diarrhea. Over 99 percent of hospitalized cases recover after an average of 3 days in the hospital, followed by 6 days of post-hospital recovery. Less than 1 percent of those hospitalized with foodborne *Shigella* infections die (fig. 18).

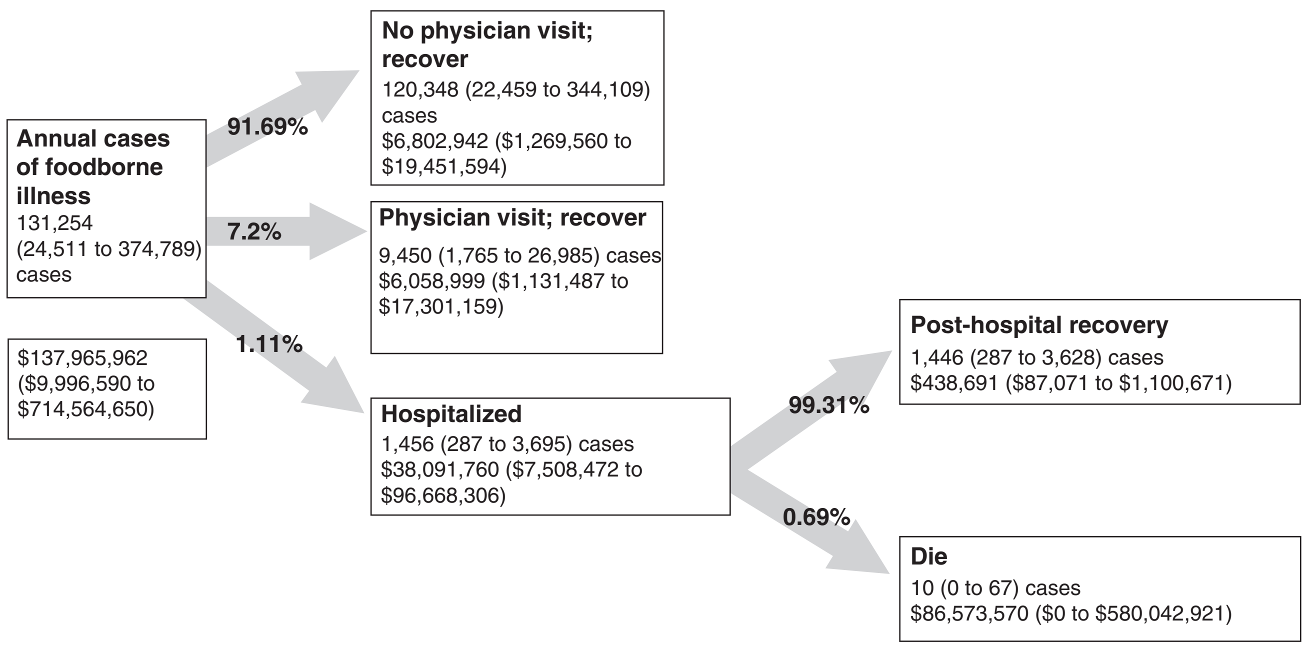
Shigella ranks 10th among the 15 pathogens included in this report both in terms of total and per-case economic burden (tables 5 and 6). It imposes an estimated $138 million in economic burden in a typical year: 63 percent of this burden ($87 million) is due to deaths, 28 percent ($39 million) to hospitalizations, and 9 percent ($13 million) to non-hospitalized cases (fig. 19).

While CDC estimates the incidence of foodborne *Shigella* infections at a little over 131,000 cases in a typical year, it could be as low as 25,000 and as high as 375,000 cases (Scallan et al., 2011a). Economic burden could range from $10 million to $715 million per year (table 6).

Figure 18

Disease-outcome tree for annual foodborne illnesses caused by *Shigella, spp*. (all species) acquired in the United States (2013 dollars)

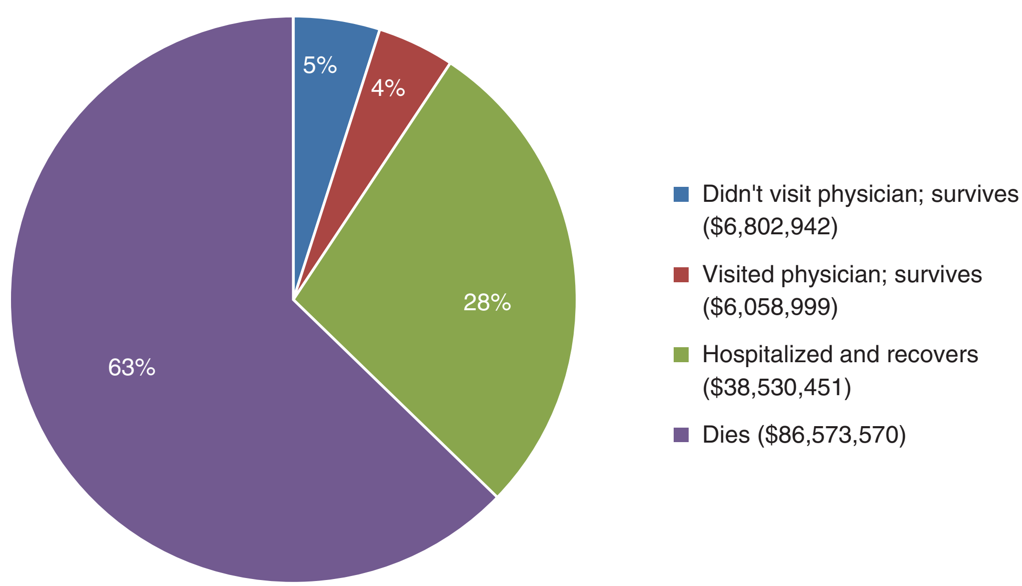
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 19

Mean economic burden of annual foodborne illnesses caused by *Shigella* (all species) acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

STEC O157

Escherichia coli (*E. coli*) are one of the most common species of bacteria in the human intestines (FDA, 2012). Most of the species are harmless or even helpful to human health. A small group of *E. coli* produce a Shiga toxin (Shiga toxin-producing *E. coli* or STEC) that can result in serious illness.

One STEC—STEC O157, which used to be called *E. coli* O157:H7—causes 63,000 cases of foodborne illness in a typical year (table 3). The pathogen causes less than 1 percent of the cases of foodborne illnesses acquired in the United States for which a specific pathogen cause can be found, but almost half these cases are hospitalized. STEC O157 causes 3.8 percent of hospitalizations and 1.5 percent of deaths (an average of 20 per year) associated with the 31 pathogens for which the CDC has provided pathogen-specific estimates of foodborne disease incidence (table 3; Scallan et al., 2011).

So why is STEC O157 in the news? For one, it is a leading cause of U.S. outbreaks of foodborne illness (Gould et al., 2013). An outbreak occurs when two or more people report illnesses that are traced to the same source of exposure. STEC O157 can cause large outbreaks. In 2006, a foodborne illness outbreak caused by STEC 0157 in fresh spinach sickened at least 199 people, 3 of whom died. Further, STEC O157 can cause very serious chronic illness, particularly in young children.

Symptoms of a STEC O157 infection usually appear 3-4 days after exposure, though the incubation period varies. Most people who are infected with STEC O157 experience mild diarrhea, abdominal cramps, and/or nausea—or no symptoms at all. Seventy-eight percent of infected people recover in an average of a day without seeing a physician (fig. 20; Batz et al., 2014). Nineteen percent of cases experience more serious symptoms, such as bloody diarrhea or more prolonged illness and seek a physician's care but are not ill enough to be hospitalized. These people typically recover in an average of 8-9 days (Batz et al., 2014).

About 3 percent of cases are serious enough to require hospitalization: 15 percent of these cases develop HUS (hemolytic uremic syndrome), a potentially life-threatening condition that involves acute kidney failure and a drop in platelet counts. HUS can be caused by the STEC and is more common in very young children and the elderly than in other adults. Ninety-three percent of those who are hospitalized with HUS due to foodborne STEC O157 infections recover after an average of 7 days of hospitalization, followed by 7 days of post-hospitalization recovery; 4 percent die (fig. 20). Three percent of those hospitalized with HUS as a result of a foodborne *E. coli* O157:H7 infection (10 cases) develop End Stage Renal Disease (ESRD), a chronic, life-threatening condition (fig. 20; Batz et al., 2014). These cases require ongoing dialysis and potentially a kidney transplant. Those with ESRD usually die before they normally would have without the disease.

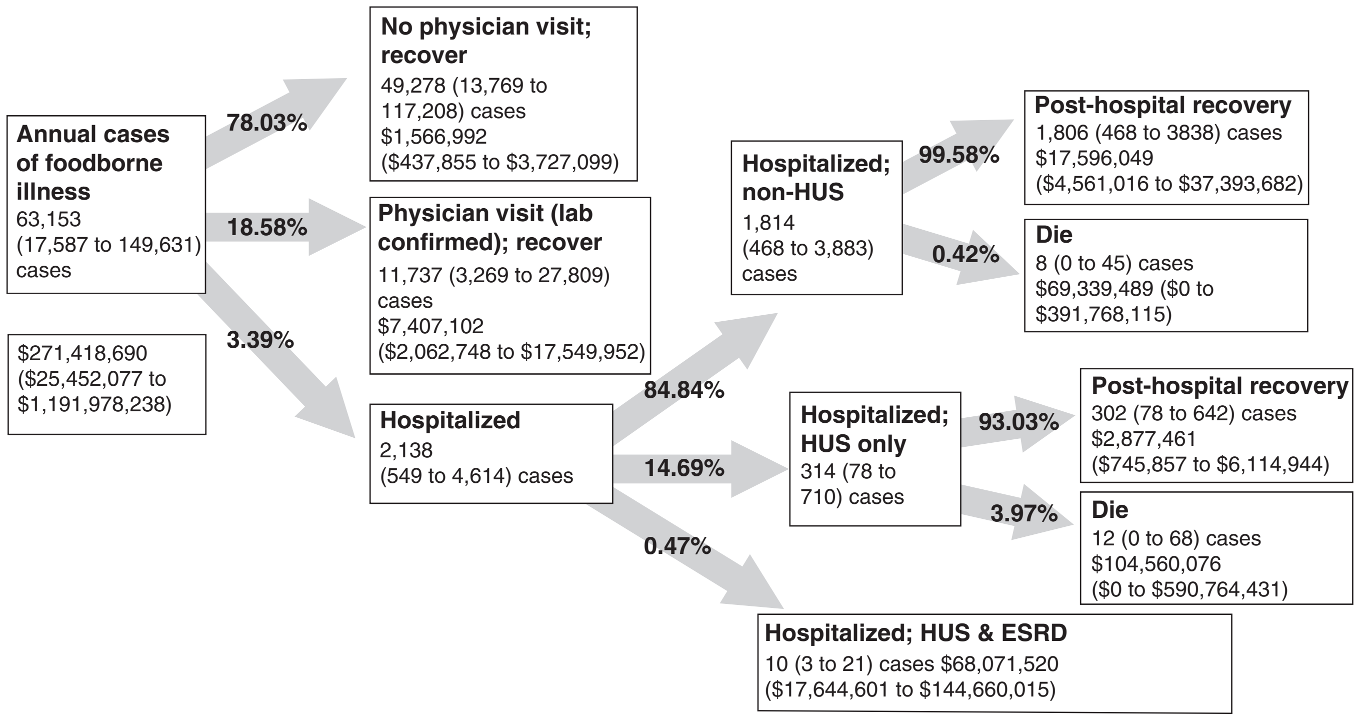
STEC O157 ranks ninth among the 15 pathogens included here in terms of economic burden, fourth on a per-case basis (tables 5 and 6). It imposes an estimated $271 million in economic burden in a typical year (table 4); 64 percent of this burden is due to the 20 deaths following hospitalization for acute illnesses that occur each year (fig. 21). Chronic kidney disease and associated future deaths account for another quarter of the economic burden imposed by STEC O157 in a typical year.

The CDC estimates the mean incidence of foodborne STEC O157 cases at 63,000 in a typical year. Again, due to modeling uncertainty, CDC estimates that incidence could be as low as 18,000 and as high as 150,000 cases in a typical year (Scallan et al., 2011a). Economic burden could range from $25 million to $1.2 billion per year (table 6). CDC's mean estimate for deaths from STEC O157 is 20 per year, but this could range from 0 to 110.

Figure 20

Disease-outcome tree for annual foodborne illnesses caused by STEC O157 acquired in the United States (2013 dollars)

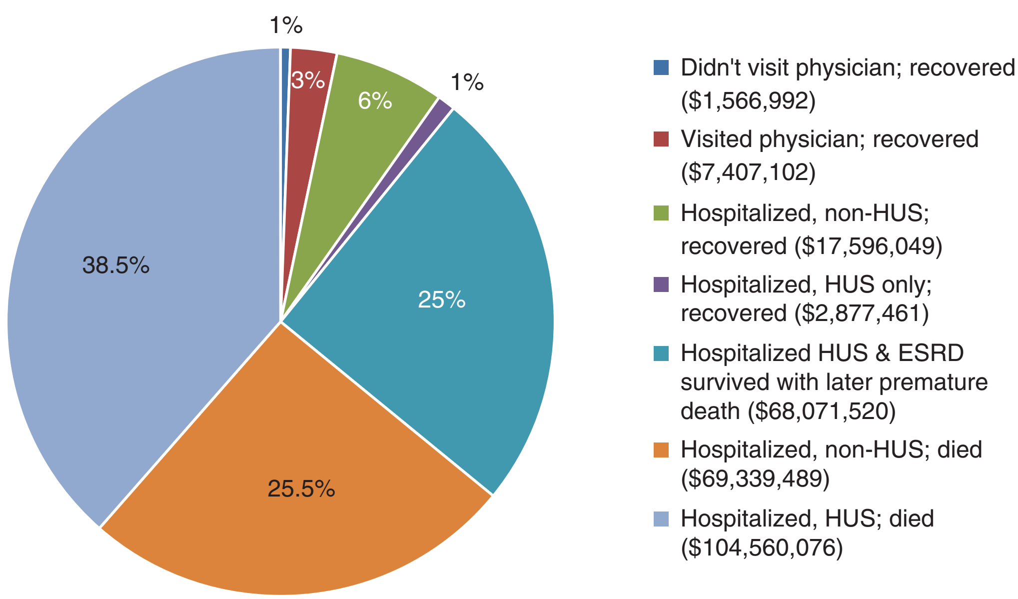
Mean cases and economic burden estimates (5th to 95th % credible interval)



STEC = Shiga toxin-producing *E. coli*; HUS = Hemolytic uremic syndrome; ESRD = End-stage renal disease.
Source: Batz et al., 2014.

Figure 21

Mean economic burden of annual foodborne illnesses caused by STEC (Shiga toxin-producing *E. coli*) O157 acquired in the United States, by health outcome (2013 dollars)



HUS = Hemolytic uremic syndrome; ESRD = End-stage renal disease. Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

STEC non-O157

There are many other Shiga-toxin producing *E. coli* (STECs) that cause disease in addition to STEC O157. These are commonly referred to as STEC non-O157. Together these pathogens cause nearly twice the number of the illnesses (112,000) as caused by STEC O157 (63,000) in a typical year. But generally, the illnesses are milder for STEC non-O157 than STEC O157; CDC estimates that there are 271 hospitalizations and no deaths from STEC non-O157 in a typical year (table 3). STEC non-O157 accounts for 1.2 percent of foodborne illnesses in the United States that can be linked to a specific pathogen and less than 0.5 percent of hospitalizations (table 3). But this group of pathogens is evolving. In 2011, a large outbreak of STEC non-O157 associated with sprouted seeds sickened more than 4,000 people in Europe, leaving 50 people dead.

Less is known about the STEC non-O157s than about STEC O157. On the whole, this group of pathogens produces health outcomes that are similar to STEC O157, with similar symptoms and durations of illness. Over 80 percent of those infected with STEC non-O157 (92,000 cases) in the United States have mild illness or no symptoms and do not seek a physician's care (fig. 22). Nineteen percent of people (21,000 cases) with these foodborne infections see a doctor but do not require hospitalization. These cases last an average of 8-9 days. Only 0.24 percent of all cases with STEC non-O157 (versus 3 percent of STEC O157 infections) require hospitalization. While a similar percentage develop hemolytic uremic syndrome (HUS, 14 percent compared to 15 percent for STEC O157), less than 0.5 percent develop End Stage Renal Disease compared to 3 percent of STEC O157 cases. Because HUS disproportionately affects children and non-working adults, per-case productivity losses associated with HUS are lower than for non-HUS cases.

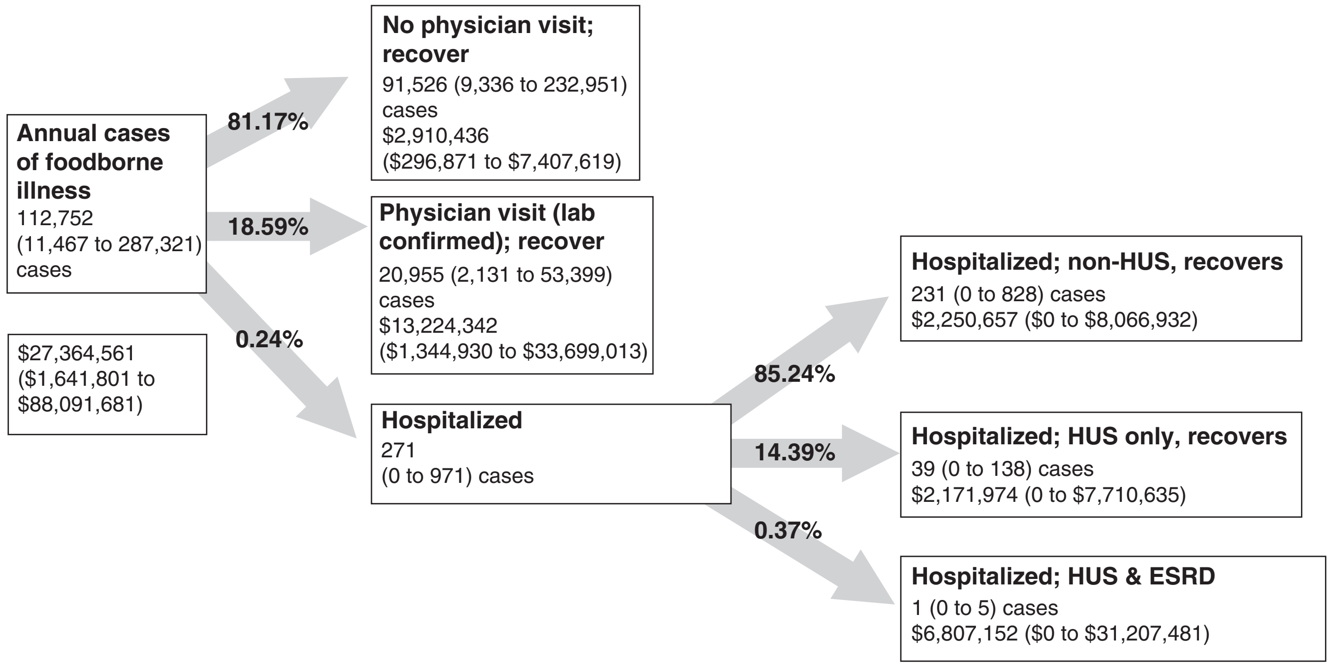
STEC non-O157 ranks 14th among the 15 pathogens included in this report in economic burden, both in terms of total and per-case burden (tables 5 and 6). It imposes an estimated $27 million in economic burden in a typical year: $13 million (48 percent) is due to non-hospitalized cases that seek a physician's care. A quarter of the burden, or $6.8 million, is due to cases that result in chronic kidney disease and premature mortality (fig. 23).

While CDC estimates the incidence of foodborne STEC non-O157 infections at 113,000 cases in a typical year, it could be as low as 11,000 and as high as 287,000 (Scallan et al., 2011a). Economic burden could range from $1.6 million to $88 million (table 6).

Figure 22

Disease-outcome tree for annual foodborne illnesses caused by STEC (Shiga toxin-producing *E. coli)* non-O157 acquired in the United States (2013 dollars)

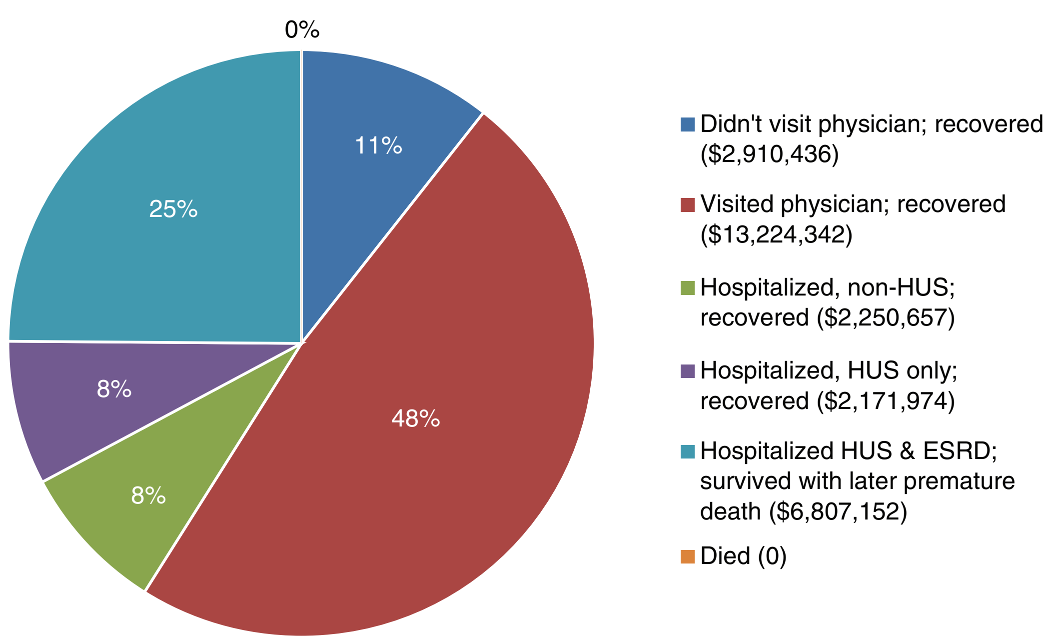
Mean cases and economic burden estimates (5th to 95th % credible interval)



HUS = Hemolytic uremic syndrome; ESRD = End-stage renal disease. Source: Batz et al., 2014.

Figure 23

Mean economic burden of annual foodborne illnesses caused by STEC (Shiga toxin-producing *E. coli*) non-O157 acquired in the United States, by health outcome



HUS = Hemolytic uremic syndrome; ESRD = End-stage renal disease.
Source: Computed by authors based on: Hoffmann et al., 2012, USDA, Economic Research Service, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Toxoplasma gondii

Toxoplasma gondii is a leading cause of death from foodborne illness acquired in the United States. Each year about 87,000 people become ill from eating food contaminated with *Toxoplasma gondii*; 327 of them die (table 3). *Toxoplasma* accounts for less than 1 percent of illnesses from foodborne illness acquired in the United States that can be linked to a specific pathogen cause, but it causes 8 percent of the hospitalizations and 24 percent of the deaths (table 3).

Toxoplasma is a single-celled parasite that can only reproduce in wild or domestic cats but spends part of its life cycle in other mammals and birds. Direct contact with cat feces is a major cause of disease from *Toxoplasma* and for many years masked the importance of this pathogen as a cause of death from foodborne illness. It is now understood that consumption of contaminated meats including pork (particularly from free-range hogs), lamb, and game are also important sources of exposure. Cases have also been caused by drinking unpasteurized goats' milk and untreated water. Cross-contamination of other foods by contaminated meat is also an important source of exposure.

Healthy adults newly infected with *Toxoplasma gondii* typically do not experience any symptoms and do not seek medical treatment (about 80 percent of all adult cases) (fig. 24a). About 14 percent of people who become infected seek medical care for acute symptoms including swollen lymph nodes, fever, muscle aches, and pain, but are not hospitalized. These symptoms can last for several weeks, but on average result in 9 days away from normal activities. Even though these healthy people infected with *Toxoplasma gondii* experience no symptoms or recover, the parasite remains in their bodies.

More than 60 million people in the United States are estimated to carry *Toxoplasma gondii*. The immune systems of healthy people are typically able to fight the parasite, but any weakening of their immune system can reactivate the disease. In adults with weakened immune systems, reactivated or new infections can lead to serious health outcomes, including encephalitis, pneumonia, inflammation of the heart, hepatitis, and impaired vision. In a typical year, about 5 percent of adult cases of illness due to foodborne *Toxoplasma gondii* infections are hospitalized (fig. 24a): 93 percent recover after an average of 9 days in the hospital and 19 days of post-hospital recovery, while 7 percent of those who are hospitalized die.

New *Toxoplasma gondii* infections in pregnant women can have serious consequences for their unborn children. Of the estimated 1,100 prenatal infections with *Toxoplasma gondii*, 68 percent never develop symptoms (Batz et al. 2014), but 1.4 percent result in stillbirths or neonatal deaths (fig. 24b). The remaining 31 percent of prenatal infections result in chronic conditions, including immediate or delayed vision impairment, and impaired motor and mental function (Batz et al., 2014). As with adult cases, information was inadequate to estimate the economic burden of the chronic consequences of *Toxoplasma gondii* infections in newborns.

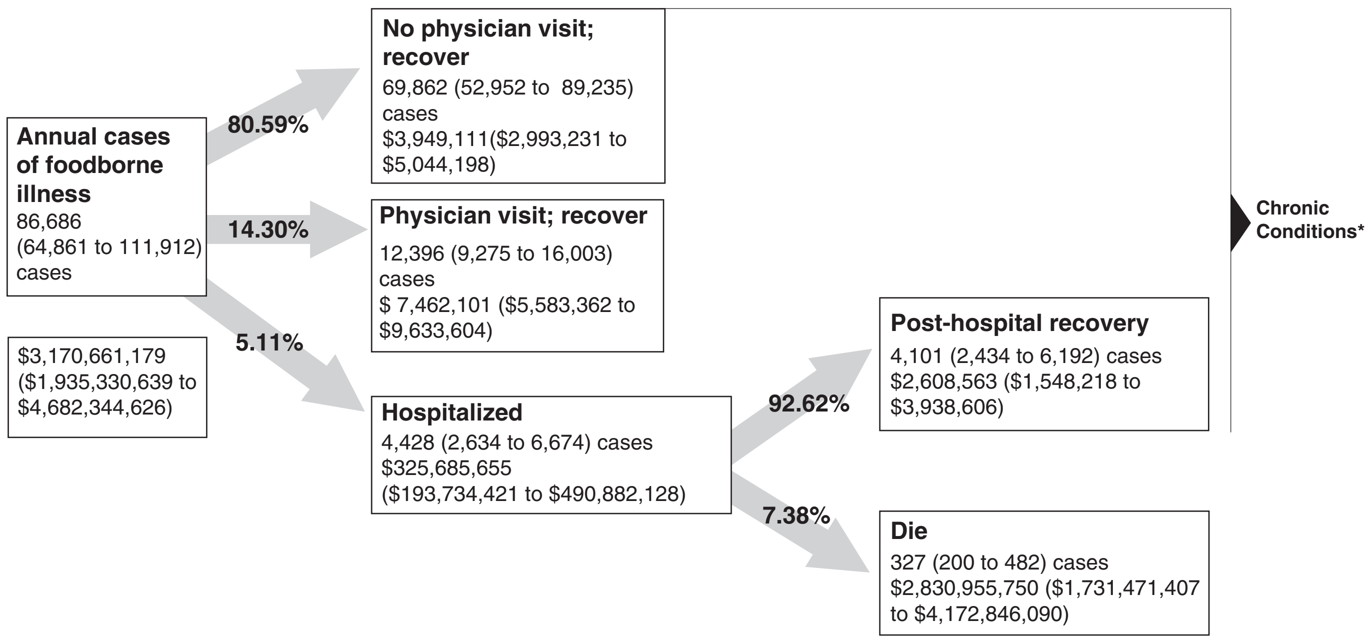
Toxoplasma gondii ranks second among the 15 pathogens included in this report in terms of total economic burden, third in per-case costs (tables 5 and 6). *Toxoplasma gondii* imposes an estimated $3.3 billion in total economic burden in a typical year (table 4). Each case imposes an average burden of $38,000. Ninety percent of the total economic burden, $3 billion, is due to deaths; $133 million of this is from neonatal deaths and stillbirths (fig. 25). Another 10 percent of total economic burden, $328 million, is due to hospitalization. These estimates do not account for chronic consequences of *Toxoplasma gondii* infections and should therefore be seen as conservative.

While CDC estimates the mean incidence of foodborne *Toxoplasma gondii* infections at about 88,000 cases in a typical year, it could be as low as 65,000 and as high as 112,000 cases (Scallan et al., 2011a). Economic burden could range from $2 billion to $4.9 billion per year (table 6).

Figure 24a

Disease-outcome tree for annual foodborne illnesses in adults caused by *Toxoplasma gondii* (adult acquired) acquired in the United States (2013 dollars)

Mean cases and economic burden estimates (5th to 95th % credible interval)

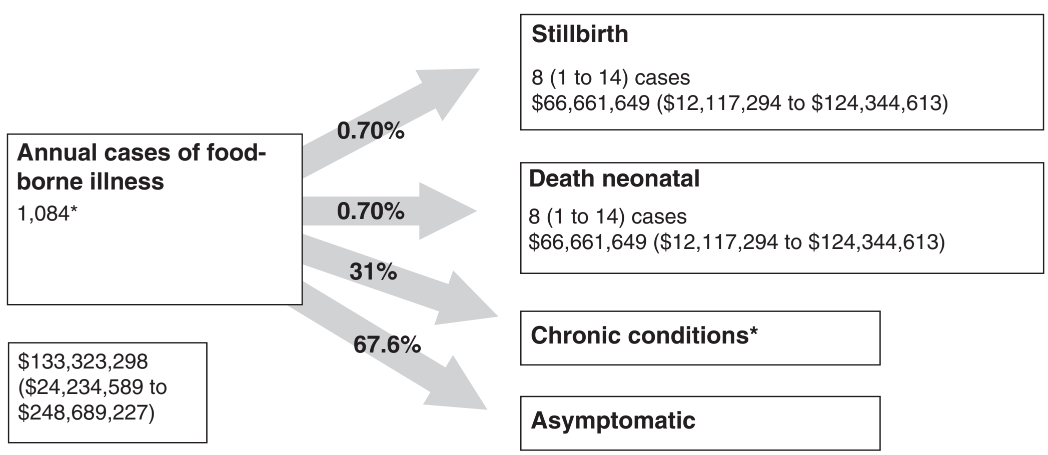


*Long-term outcomes have been associated with Toxoplasma gondii infections. At this time we do not have underlying research adequate to include chronic consequences of Toxoplasma gondii infections in our cost of illness estimates.
Source: Batz et al., 2014.

Figure 24b

Disease-outcome tree for annual congenital foodborne illnesses caused by *Toxoplasma gondii* acquired in the United States (2013 dollars)

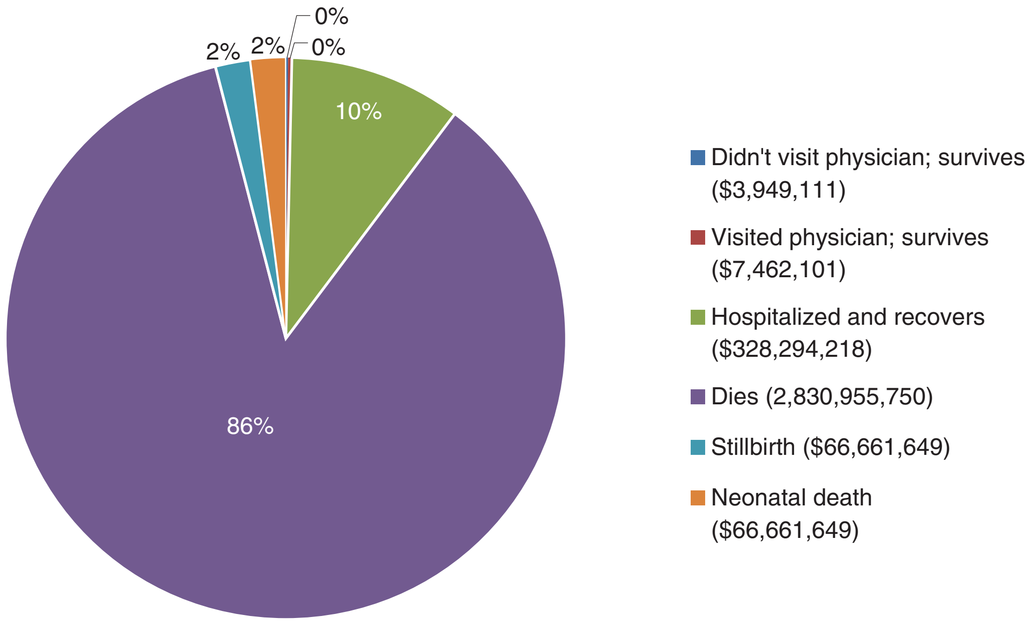
Mean cases and economic burden estimates (5th to 95th % credible interval)



*Long-term outcomes have been associated with Toxoplasma gondii infections. At this time, we do not have underlying research adequate to include chronic consequences of *Toxoplasma gondii* infections in our cost of illness estimates.
Source: Batz et al., 2014.

Figure 25

Mean economic burden of annual foodborne illnesses caused by *Toxoplasma gondii* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

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Vibrio parahaemolyticus

In the United States, *Vibrio parahaemolyticus* is predominantly foodborne (86 percent foodborne), but the pathogen causes only about 0.2 percent of the foodborne illnesses (35,000 cases) for which a specific pathogen cause can be identified (table 3). Because *Vibrio parahaemolyticus* needs to live in saltwater, raw oysters and other raw seafood or seafood contaminated by other raw seafood are the most frequent causes of exposure. *Vibrio parahaemolyticus* infections are generally mild. Only 100 out of 35,000 illnesses a year require hospitalization. On average, four people die from this infection in a typical year (table 3).

Symptoms from *Vibrio parahaemolyticus* infections typically appear within 24 hours of eating contaminated food. The pathogen causes watery diarrhea, cramps, nausea, vomiting, fever, and chills. Eighty-seven percent of those with the infection recover without medical care in an average of 2 days (fig. 26). In 13 percent of cases, those affected seek medical care, but do not require hospitalization. Of those requiring hospitalization, 96 percent recover. On average, hospitalization lasts 9 days and is followed by 18 days of post-hospitalization recovery. Infections from *Vibrio parahaemolyticus* do not generally result in long-term health consequences.

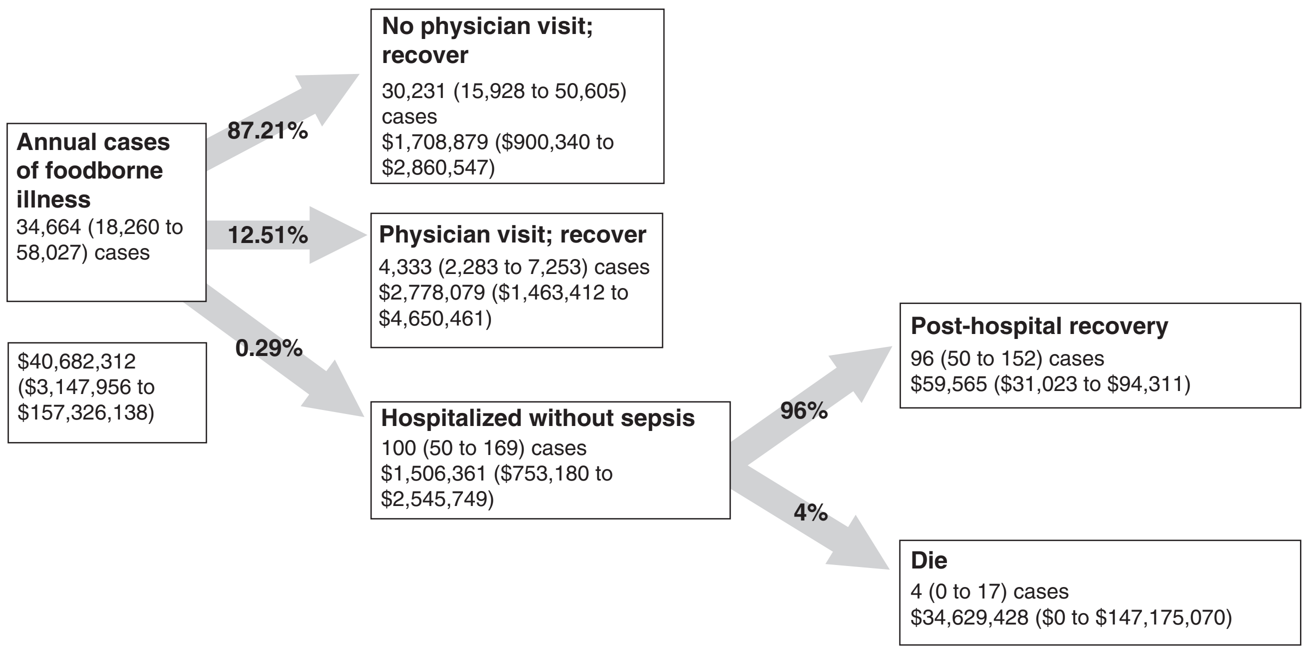
Vibrio parahaemolyticus ranks 13th among the 15 pathogens included in this report in terms of total economic burden, 9th on a per-case basis (tables 5 and 6). It imposes an estimated $41 million in economic burden in a typical year (table 4), 85 percent of which is due to deaths. Another 4 percent, $1.6 million, is due to hospitalization (fig. 27).

While CDC estimates the mean incidence of foodborne *Vibrio parahaemolyticus* infections at a little under 35,000 cases in a typical year, it could be as low as 18,000 and as high as 58,000 cases (Scallan et al., 2011a). Economic burden could range from $3 million to $157 million per year (table 6).

Figure 26

Disease-outcome tree for annual foodborne illnesses caused by *Vibrio parahaemolyticus* acquired in the United States (2013 dollars)

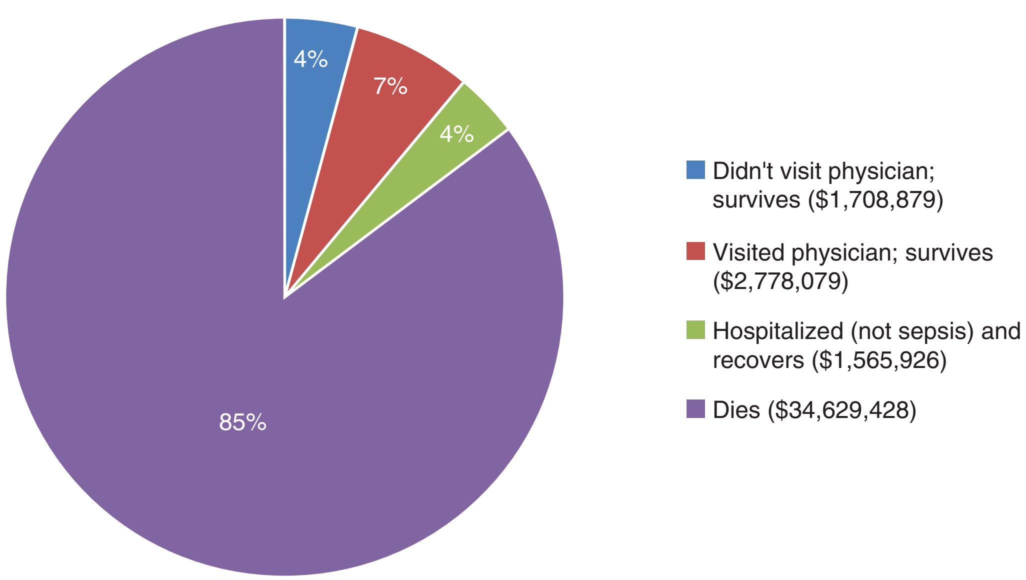
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 27

Mean economic burden of annual foodborne illnesses caused by *Vibrio parahaemolyticus* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al. 2012, USDA ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Vibrio vulnificus

Vibrio vulnificus is another bacteria in the same genus as *Vibrio parahaemolyticus*. Like *V. parahaemolyticus*, it lives in salt water or in estuaries where salt and fresh water mix. People can become infected by *V. vulnificus* by eating contaminated seafood (typically raw oysters) or by swimming in contaminated water with open wounds (CDC, 2014). Healthy people who are exposed may not develop an infection. Illness occurs more frequently in those with pre-existing health conditions that impair their immune system, and even more commonly in those with impaired liver function.

Foodborne *V. vulnificus* infections are rare, but very serious. There are fewer than 100 cases of foodborne infection with *Vibrio vulnificus* acquired in the United States in a typical year (table 3), but almost 40 percent of those who become ill die. As a result of this high death rate, *Vibrio vulnificus* accounts for almost 3 percent of the deaths from foodborne infections acquired in the United States for which a specific pathogen cause can be identified, even though it accounts for only 0.001 percent of the foodborne illnesses acquired (table 3).

The symptoms of *Vibrio vulnificus* infections usually appear 12 hours to 21 days after exposure (FDA, 2012). Symptoms include vomiting, diarrhea, and abdominal pain, and are generally severe enough that virtually all people seek medical care. About 3 percent of cases recover without hospitalization following an illness that lasts an average of 2 days. About 97 percent of cases result in hospitalization; of these, 80 percent develop sepsis (fig. 28). Sepsis starts when an infection spreads into the blood stream. Almost 50 percent of those who develop sepsis as a result of a foodborne *Vibrio vulnificus* infection die. Those who recover are hospitalized for an average of 7 days in ICU and another 7 days outside of ICU; hospitalization is followed by a post-hospitalization recovery that averages 42 days. Those who survive *Vibrio vulnificus* do not generally have further long-term complications.

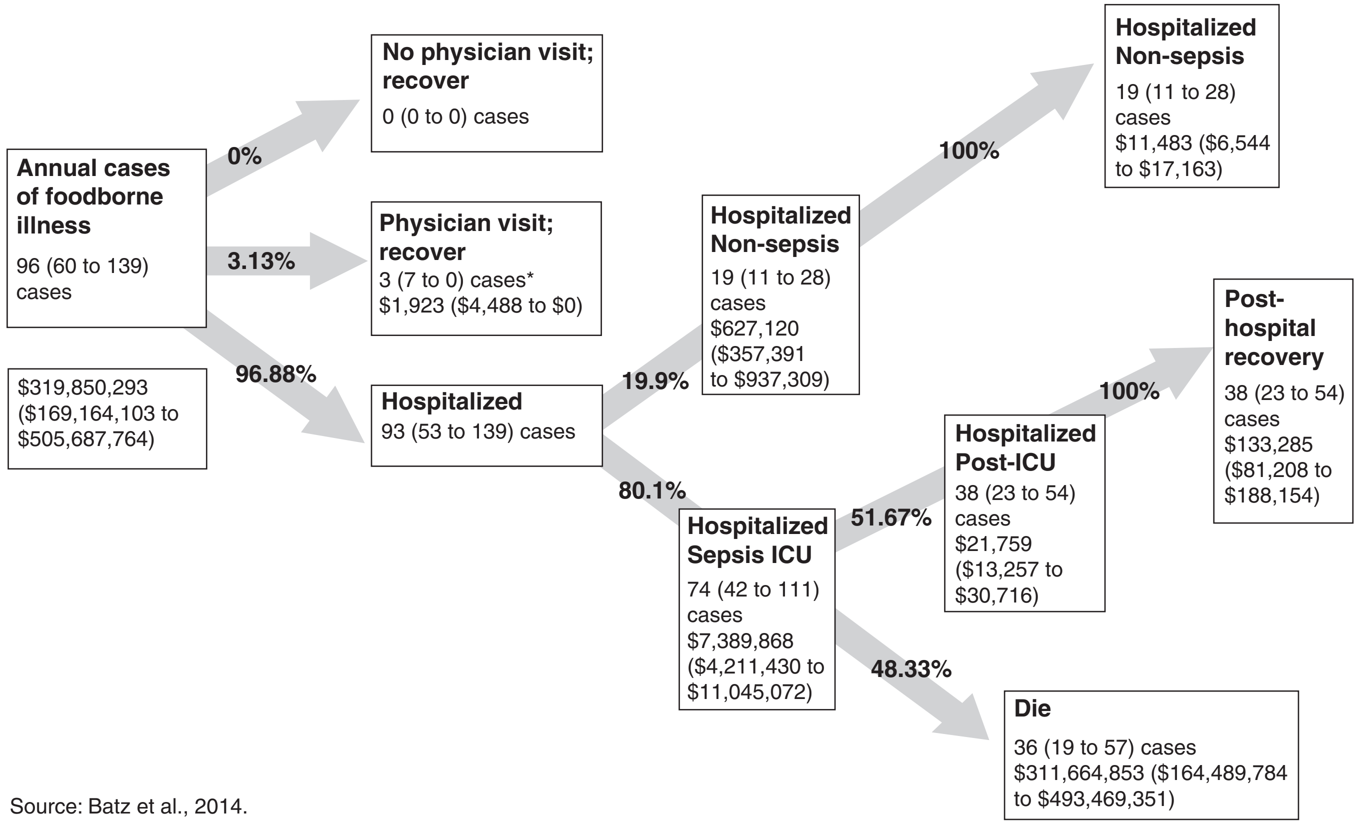
Vibrio vulnificus ranks 7th among the 15 pathogens included in this report in terms of total economic burden, 1st on a per-case basis (table 5). It imposes an estimated $320 million in economic burden in a typical year (table 4). Each case imposes a burden of $3.3 million (table 5), 98 percent of which is due to deaths (fig. 29). About 2 percent of the burden ($7.5 million) is due to hospitalization with sepsis.

While CDC estimates the mean incidence of foodborne *Vibrio vulnificus* infections at 96 cases in a typical year, it could be as low as 60 cases and as high as 139 cases (Scallan et al., 2011a). Economic burden could range from $169 million to $506 million per year (table 6). The confidence bound around the incidence estimate for this pathogen is fairly narrow; due to the severity of the illness, the likelihood of reporting and diagnosis is much higher than for most pathogens.

Figure 28

Disease-outcome tree for annual foodborne illnesses caused by *Vibrio vulnificus* acquired in the United States (2013 dollars)

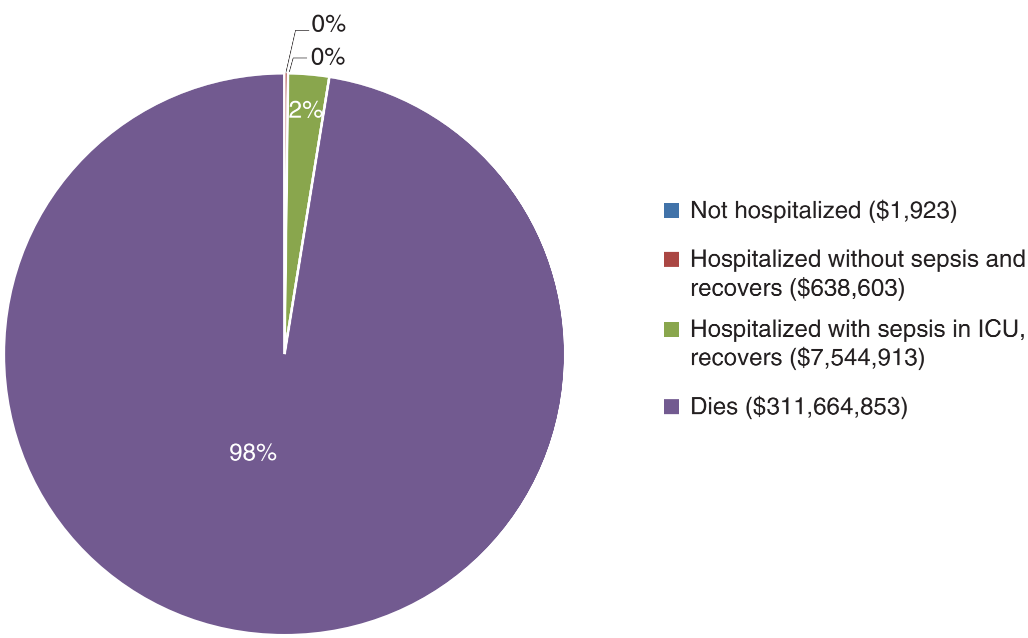
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 29

Mean economic burden of annual foodborne illnesses caused by *Vibrio vulnificus* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Vibrio non-cholera species other than *V. parahaemolyticus* and *V. vulnificus*

Vibrio (V.) species other than *V. parahaemolyticus, V. vulnificus,* and the *Vibrio* species that cause cholera (a rare disease in the United States) sicken about 18,000 people in a typical year (table 3). While the hospitalization rate for these species is slightly higher than for *V. parahaemoliticus*, it is significantly lower than for *V. vulnificus*. Each year, approximately 83 people are hospitalized with infection by these other *Vibrio* species and about 8 people die (table 3). These species of *Vibrio* cause about 1 percent of the cases and hospitalizations and 2 percent of the deaths from food-borne illness acquired in the United States for which a specific pathogen cause can be identified. Foodborne infections from these other species of *Vibrio* cause about 1 percent of the cases/hospitalizations and 2 percent of the deaths associated with foodborne illnesses (table 3).

These other *Vibrio* species cause infections that are very similar to those caused by *Vibrio parahaemolyticus* in symptoms, severity, and duration of illness. The hospitalization rate for these other *Vibrio* species is slightly higher than for *Vibrio parahaemolyticus,* but still less than 0.5 percent of cases (fig. 30). Those hospitalized rarely develop sepsis and recover after a hospital stay of 9 days, followed by a post-hospitalization recovery of 18 days on average. The death rate for these other *Vibrio* species is also slightly higher than for *Vibrio parahaemolyticus*; about 10 percent of those hospitalized die. Like *Vibrio parahaemolyticus* and *Vibrio vulnificus*, these other *Vibrio* species cause acute illness and are not associated with long-term health consequences.

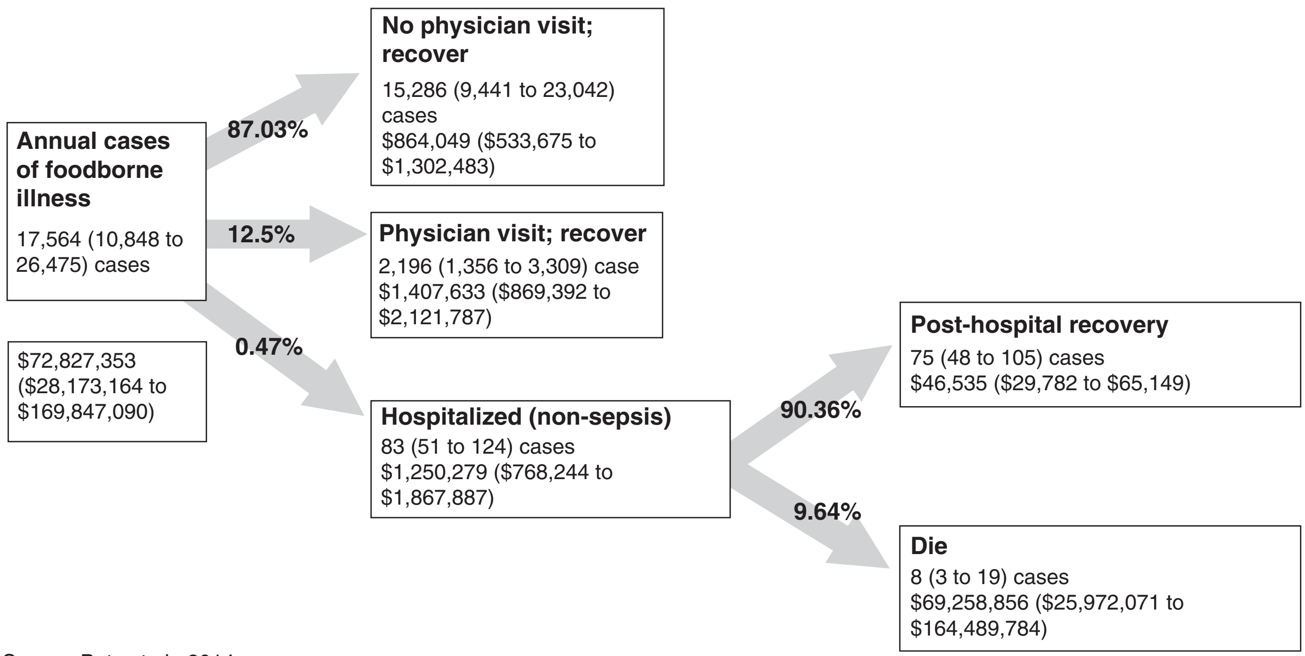
Other non-cholera *Vibrio* species ranks 11th among the 15 pathogens included in this report in total economic burden (table 4), 5th in per-case costs at about $4,100 (table 5). These species impose an estimated $73 million in economic burden in a typical year (table 4); 95 percent of this burden, $69 million, is due to deaths (fig. 31).

While the CDC estimates the mean incidence of foodborne non-cholera *Vibrio* species infections at about 18,000 cases in a typical year, it could be as low as 11,000 and as high as 26,000 cases (Scallan et al., 2011a). Economic burden could range from $28 million to $170 million (table 6).

Figure 30

Disease-outcome tree for annual foodborne illnesses caused by Vibrio non-cholera species other than *V. parahaemolyticus* and *V. vulnificus* acquired in the United States (2013 dollars)

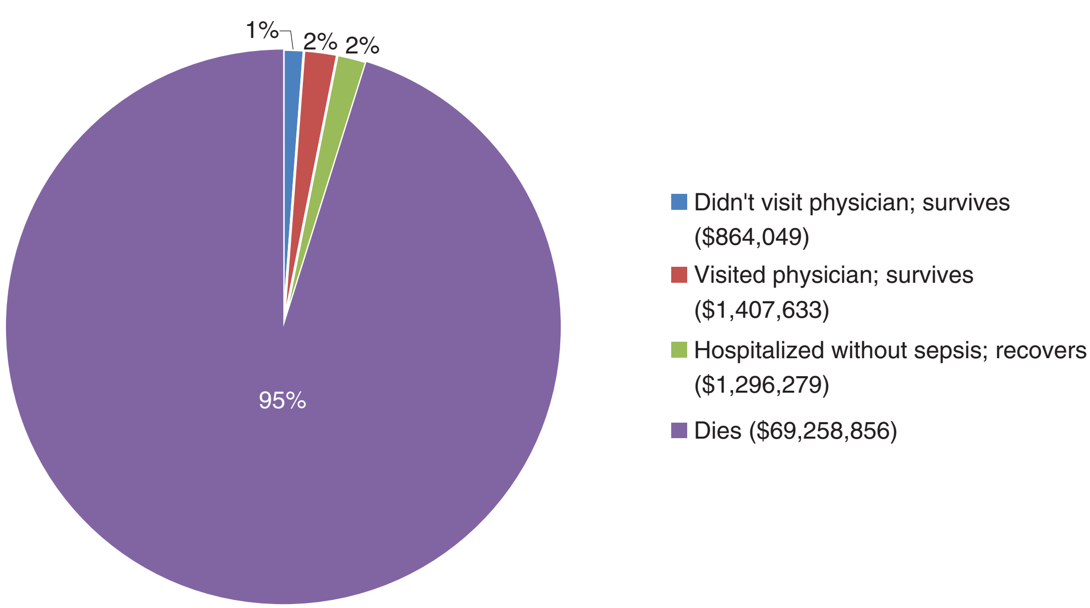
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 31

Mean economic burden of annual foodborne illnesses caused by *Vibrio vulnificus* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

Yersinia enterocolitica

In a typical year, 98,000 people will be infected by foodborne *Yersinia enterocolitica* in the United States and 533 will be hospitalized (table 3), resulting in 29 deaths. The pathogen causes 1 percent of the illnesses and hospitalizations and 2 percent of the deaths due to foodborne infections contracted in the United States that can be linked to a specific pathogen (table 3). Most *Yersinia enterocolitica* infections are caused by eating contaminated food, particularly undercooked pork products. Outbreaks have also been associated with unpasteurized milk and untreated water. *Yersinia enterocolitica* can survive in frozen foods and can grow while refrigerated.

Symptoms from *Yersinia enterocolitica* infections typically appear 1 to 4 days after eating contaminated food. *Yersinia* generally causes mild illness, lasting 2 days; 87 percent of those infected recover without seeing a physician (fig. 32). Symptoms generally include abdominal pain and fever with watery diarrhea. Children are more apt to have bloody diarrhea. Older children and adults may experience sharp abdominal pain that can be confused with appendicitis. About 12 percent of cases see a physician, but recover without hospitalization after being ill for an average of 5 days (fig. 33). Approximately 0.6 percent of cases are hospitalized. Of these, two-thirds develop sepsis, a potentially life-threatening complication from bacterial infections. About 8 percent of those who develop sepsis following a foodborne infection with *Yersinia enterocolitica* die (fig. 33). The remainder survive following, on average, a 15-day hospitalization and a 30-day home recovery. About 12 percent of those hospitalized are misdiagnosed with appendicitis and undergo an appendectomy.

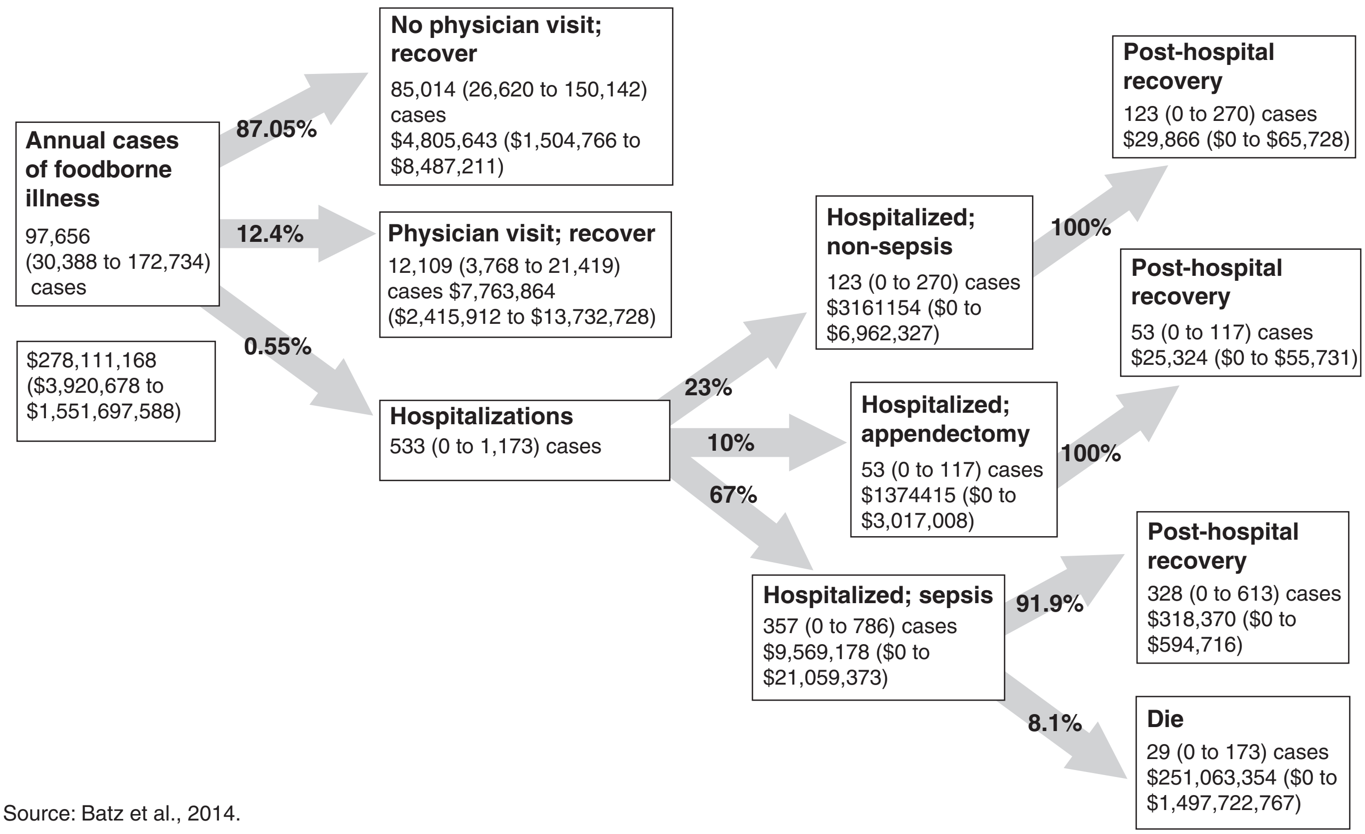
Yersinia ranks 8th among the 15 pathogens included in this report in terms of total economic burden, and 7th on a per-case basis (tables 5 and 6). It imposes an estimated $278 million in economic burden in a typical year (table 4), 90 percent of which is due to deaths (fig. 33).

While CDC estimates the mean incidence of foodborne *Yersinia* infections at a little under 98,000 cases in a typical year, it could be as low as 30,000 and as high as 173,000 cases (Scallan et al., 2011a). Economic burden could range from $3.9 million to $1.6 billion (table 6).

Figure 32

Disease-outcome tree for annual foodborne illnesses caused by *Yersinia enterocolitica* acquired in the United States (2013 dollars)

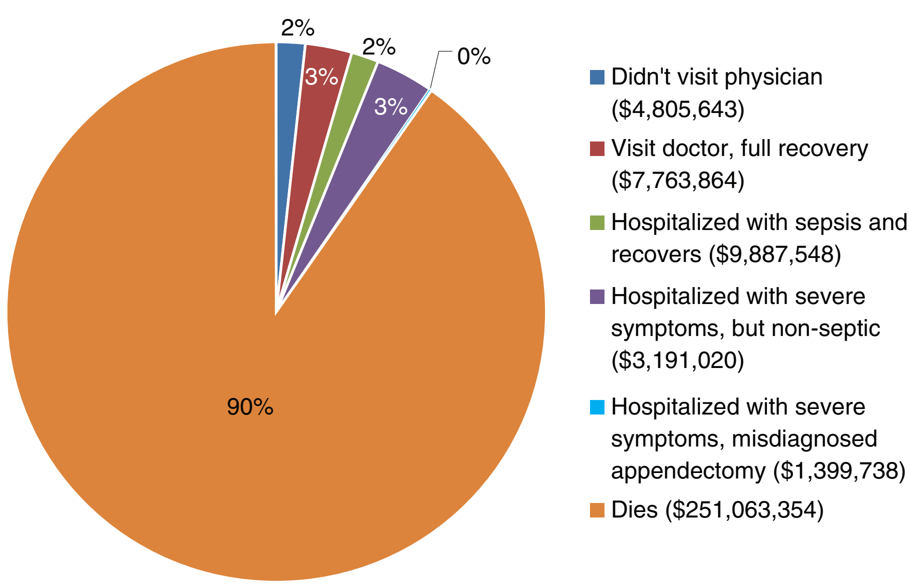
Mean cases and economic burden estimates (5th to 95th % credible interval)



Source: Batz et al., 2014.

Figure 33

Mean economic burden of annual foodborne illnesses caused by *Yersinia enterocolitica* acquired in the United States, by health outcome (2013 dollars)



Source: Computed by authors based on: Hoffmann et al., 2012, USDA, ERS, Cost Estimates of Foodborne Illnesses [http://www.ers.usda.gov/data-products/cost-estimates-of-foodborne-illnesses.aspx].

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