



Published in final edited form as:

Epidemiol Infect. 2015 July ; 143(9): 2003–2013. doi:10.1017/S0950268814003112.

Outbreaks of *Salmonella* Infections Attributed to Beef – United States, 1973–2011

A.S. Laufer^{1,2}, J. Grass², K. Holt³, J.M. Whichard⁴, P.M. Griffin², and L.H. Gould²

¹Epidemic Intelligence Service, Division of Scientific Education and Professional Development, CSELS, CDC, Atlanta, GA

²Enteric Diseases Epidemiology Branch, DFWED, NCEZID, CDC, Atlanta, GA

³Food Safety and Inspection Service, USDA, Washington, DC

⁴Enteric Diseases Laboratory Branch, DFWED, NCEZID, CDC, Atlanta, GA

Summary

Nontyphoidal salmonella is estimated to be the most common bacterial cause of foodborne illness in the United States, causing an estimated one million domestically-acquired foodborne illnesses annually. Recent, large outbreaks have highlighted the importance of ground beef as an important source of multidrug resistant salmonella. We analysed the epidemiology of salmonellosis outbreaks that were attributed to beef in the United States reported to the Centers for Disease Control and Prevention (CDC) from 1973 through 2011. During 1973–2011, of the 1965 outbreaks of salmonella where a food vehicle was implicated, 96 were attributed to beef, accounting for 3684 illnesses. We observed a shift in the type of beef implicated in salmonellosis outbreaks, from roast to ground beef. Delicatessen-style roast beef cooked in commercial processing establishments was the predominant type during the 1970s and early 1980s; regulations on cooking and processing essentially eliminated this problem by 1987. Ground beef emerged as an important vehicle in the 2000s; it was implicated in 17 (45%) of the 38 beef-attributed outbreaks reported during 2002–2011. Although this emergence was likely due in part to increased participation in CDC's PulseNet, which was established in 1996, and proactive decisions by the United States Department of Agriculture's Food Safety and Inspection Service, stronger measures are needed to decrease contamination of ground beef with salmonella.

Keywords

Salmonella enterica; Food-borne infections; Food safety; Antibiotic resistance; Outbreaks

Manuscript Corresponding Author: Alison S. Laufer, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, Mail Stop A-31, Atlanta, GA 30333, VIF0@cdc.gov.

Correspondence Author for reprints: Alison S. Laufer, Centers for Disease Control and Prevention, 1600 Clifton Rd NE, Mail Stop A-31, Atlanta, GA 30333, ALAUFER@cdc.gov

Disclaimers: The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

Conflict of interest: None

Introduction

Nontyphoidal salmonella is estimated to be the most common cause of bacterial foodborne illnesses in the United States, causing an estimated one million foodborne illnesses and about 130 outbreaks annually [1, 2]. Despite efforts to prevent salmonella contamination of foods, the incidence of salmonella infections, as reported by the Foodborne Diseases Active Surveillance Network (FoodNet), did not decrease between 1996 and 2011 [3]. An analysis based on outbreak data from 1998 through 2008 estimated beef to be the third most common source of U.S. bacterial foodborne illness and the fourth most common source of salmonella outbreaks attributed to a commodity after poultry, eggs, and pork [4]. Recent, large outbreaks of Salmonella, including some caused by multidrug resistant strains, have highlighted the role of beef, particularly ground beef, as an important source of foodborne infections [5–7].

Cattle are known reservoirs of salmonella, which can contaminate meat during slaughter and subsequent processing steps [8]. In 1998, the United States Department of Agriculture's Food Safety and Inspection Service (USDA-FSIS) implemented a beef carcass and ground beef salmonella testing programme to verify that establishments were maintaining process control and were meeting performance standards [9]. Testing by USDA-FSIS during the 2000s showed <3% of ground beef samples are positive for salmonella, in contrast to 7.5% in 1993–1994 [9, 10]. Each year in the United States, over 26 billion pounds of beef are consumed [11], and in one survey, 18% of persons who reported consuming ground beef in the previous 7 days indicated that it was raw or undercooked [12]. Based on a court ruling, USDA-FSIS cannot consider salmonella to be an adulterant of raw beef because the product is expected to be handled properly and adequately cooked before consumption, thereby destroying pathogens [13]. In select situations where illnesses are linked to a raw meat, FSIS has made determinations that the product was adulterated and product was recalled by the processor [14]. Salmonella outbreaks attributed to beef have not been previously described. In this report, we describe and analyse salmonellosis outbreaks in the United States that were attributed to beef and reported from 1973 through 2011.

METHODS

State, local, and territorial health departments have voluntarily submitted reports of foodborne disease outbreak investigations to the CDC's Foodborne Disease Outbreak Surveillance System (FDOSS) (www.cdc.gov/foodsafety/fdoss) since 1973. We queried FDOSS for reports of outbreaks of salmonella infections from 1973 through 2011 in which beef was listed as the implicated food vehicle. We also searched Morbidity and Mortality Weekly Reports (MMWR), along with the Embase, MEDLINE, and Web of Science databases using the following keywords: salmonella, salmonella food poisoning/infection/outbreak, and beef; an additional six outbreaks that occurred between 1975 and 1996 were identified and were included in the analysis [15–18].

A foodborne disease outbreak is defined by CDC as the occurrence of two or more cases of a similar illness resulting from the ingestion of a common food. Outbreaks were included in the analysis if salmonella was the only reported aetiology and if the implicated food was

beef or a food containing beef, like tacos, where the contaminated ingredient was identified as beef.

Since 2003, CDC's National Antimicrobial Resistance Monitoring System (NARMS) laboratory has performed antimicrobial susceptibility tests on representative clinical isolates from outbreak investigations [19]. Antimicrobial susceptibility results from NARMS were included in the analysis when available. Additionally, the results of antimicrobial susceptibility testing were included from the published literature for six outbreaks [5–8, 20, 21]. Clinical and Laboratory Standards Institute (CLSI) interpretive criteria were used when available [19].

Variables included in outbreak reports and used in descriptive analyses included number of outbreaks, illnesses, and hospitalizations, patient demographics (age, gender), nontyphoidal *Salmonella* species and serotype, month and year of outbreak, food preparation settings, factors contributing to food contamination (complete list of factors available at http://www.cdc.gov/nors/pdf/NORS_Guidance_5213-508c.pdf), traceback investigations, and products recalled. Multiple food preparation settings could be reported; all preparation settings reported in each outbreak were included in the descriptive analysis. We classified the beef products implicated into four mutually exclusive categories: roast beef, ground beef, other beef types and unknown beef type.

Contributing factors were grouped into five categories according to whether they represented contamination of raw ingredients or foods before food preparation (environmental contamination), contamination or amplification during food preparation and processing, such as inadequate time or temperature during cooking (improper food handling), direct contamination of food by a food handler who was ill or a carrier of the pathogen (worker contamination), cross-contamination in the food preparation environment (cross-contamination), or other contamination factors (other contamination). More than one contributing factor could be reported. All contributing factors reported in each outbreak were included in the descriptive analysis.

Statistical tests were performed using nonparametric methods when sample size was sufficient, including Wilcoxon rank sum test and Fisher's exact chi-squared test. Statistical analyses were done using SAS 9.3 (Cary, NC).

RESULTS

From 1973 through 2011, 28599 foodborne outbreaks were reported to CDC. Of the 1965 outbreaks reported to CDC where salmonella was the aetiological agent and a food vehicle was implicated, beef was the implicated food vehicle in 90 outbreaks. Including the six additional outbreaks reported in the literature, 96 beef attributed salmonellosis outbreaks in total were identified. These 96 outbreaks accounted for 3684 illnesses, 318 hospitalizations, and 5 deaths (Table 1). All outbreaks were due to *Salmonella enterica*. A serotype was reported for 89 (93%) outbreaks (Table 2). Thirty serotypes caused outbreaks, most commonly Typhimurium (16 outbreaks, 17%), Newport (15, 16%), and Enteritidis (9, 9%). Outbreaks caused by serotypes Newport and Typhimurium also accounted for more illnesses

(656, 18%; 614, 17%) and hospitalizations (93, 29%; 58, 18%) than any other single serotype. A median of two outbreaks (range, 0–9) and 63 outbreak-related illnesses (range, 0–200) were reported each year. No changes over time in the number of outbreaks reported annually were apparent (Figure 1). The median size of these outbreaks was 29 illnesses (range 2–200) (Table 1). The largest outbreak reported to CDC, a multistate outbreak of 200 *Salmonella* serotype Newport infections associated with roast beef, occurred in 1977 [22].

Beef types implicated in outbreaks

Roast beef was implicated in 26 (27%) outbreaks, ground beef in 22 (23%), and other types in 30 (31%); the type was not specified in the remaining 18 (19%). In 13 (93%) of 14 roast beef-attributed outbreaks with information available on the preparation of the roast beef, the beef was pre-cooked, delicatessen-style. Steak (8 outbreaks), jerky (7), and brisket (7) were the types most commonly implicated in outbreaks in the other types of beef category. *Salmonella* serotypes Typhimurium and Newport accounted for over half (59%) of the ground beef-attributed outbreaks, and Typhimurium accounted for 28% of outbreaks caused by unknown beef type, whereas no serotype predominated in outbreaks attributed to roast beef or other types of beef. Outbreaks differed in size by type of beef (median: 47 illnesses per outbreak for roast, 36 for ground, 15 for other types, and 19 for unknown types) (Table 1). For 36 outbreaks with information available on the gender and age of patients, the percentage of patients who were female did not differ significantly by beef type (Wilcoxon rank sum test, $P=0.53$); overall, 52% of patients were female. Differences in the age distribution of patients by type of beef were not apparent; overall, 50% were aged 20 to 49 years (range by type: 44%–59%).

Roast beef-attributed outbreaks were more common in the first half of the surveillance period; 21 (81%) of 26 roast-attributed outbreaks were reported during 1973–1991. In contrast, ground beef emerged as the predominant type in 2002; 17 (77%) of 22 ground beef-attributed outbreaks were reported during 2002–2011. In addition, ground beef was responsible for 17 (45%) of 38 outbreaks reported during 2002–2011 (Figure 1). The distribution of ground beef- and roast beef-attributed outbreaks pre-1993 versus post-1993 was significantly different (Fisher's exact test, $P<.0001$). Outbreaks attributed to other types of beef were first reported in 1985 and occurred throughout the study period.

The number of outbreaks reported varied by month, increasing in May, reaching a peak in August, and dropping sharply in November (Figure 2). With one exception, roast beef-attributed outbreaks were reported during April through September. The majority of ground beef-attributed outbreaks were reported during May through October. Outbreaks were reported throughout the year for other or unknown beef type.

Geography of and multistate outbreaks attributed to beef

Outbreaks occurred in 46 states and Washington, D.C., with the most reported from New York (18 outbreaks), California (14) and Wisconsin (10) (Figure 3). Traceback investigations were performed in six outbreaks; two outbreaks, in 2002 and 2003, were traced back to the same large slaughterhouse [23]. Of the six outbreaks in which traceback

investigations were performed, product was recalled in one; product was recalled in an additional three outbreaks.

Eleven multistate outbreaks were reported, involving a median of four states reporting cases (range, 2–15) and were caused by serotypes Newport (6 outbreaks), Typhimurium (3), Berta (1) and Bovismorbificans (1). Ground beef was implicated in nine of eleven (82%) multistate outbreaks, all but two of which occurred after 2001; two were linked to roast beef and occurred in 1976 and 1977. Although multistate outbreaks accounted for only 11% of reported outbreaks and 19% (697) of illnesses, they accounted for a disproportionately larger number of multidrug resistant outbreaks (11, 79%), hospitalizations (93, 29%), and deaths (2, 40%) than single state outbreaks.

Preparation settings reported in outbreaks

Reports of 88 (92%) outbreaks included data on settings where food was prepared (Table 1). The most common overall were restaurants or delicatessens (35, 40%) and private homes (25, 28%). In outbreaks involving roast beef, the most common preparation settings were restaurants or delicatessens (10, 42%, all but three during 1975–1988) and processing plants (9, 38%, the last identified in 1986); only one roast beef-attributed outbreak report indicated a private home as the preparation setting. In contrast, the most common food preparation setting in outbreaks involving ground beef was a private home (12, 63%).

Contributing factors reported for outbreaks

At least one contributing factor was reported for 31 (67%) of the 46 outbreaks reported during 1998 to 2011 (Table 1). Improper food handling (67%) and environmental contamination (61%) were the most common, followed by cross-contamination (45%), worker contamination (23%), and other contamination (6%). environmental contamination was reported in over half the ground beef-attributed outbreaks (59%) but not in any roast beef-attributed outbreaks. Conversely, cross-contamination was reported in 3 (75%) of the 4 roast beef-attributed outbreaks versus 2 (12%) of 17 ground beef-attributed outbreaks. The most commonly reported contributing factor for outbreaks attributed to other beef types was improper food handling (50%).

Antimicrobial susceptibility results for outbreak strains

Antimicrobial resistance data were available for 14 outbreaks. Strains from six outbreaks were susceptible to all agents tested and were caused by serotypes Typhimurium (2 outbreaks), Anatum (1), Berta (1), Montevideo (1), Newport (1); the beef types were ground (3 outbreaks), roast (2) and other: barbecued (1). Strains from the other eight outbreaks were resistant to at least three classes of antimicrobial agents; all these outbreaks were due to ground beef. Five were caused by serotype Newport, including two resistant to ampicillin, chloramphenicol, streptomycin, sulfamethoxazole/sulfisoxazole, tetracycline, amoxicillin-clavulanic acid, ceftriaxone (ACSSuTAuCx) and one only resistant to ACSSuT (ampicillin, chloramphenicol, streptomycin, sulfamethoxazole/sulfisoxazole, tetracycline); three were caused by serotype Typhimurium, including one resistant to ACSSuTAuCx and one only resistant to ACSSuT. The median percentage of patients hospitalized was higher in outbreaks caused by resistant strains (median: 23%, range: 4–40), than in outbreaks caused

by strains with no resistance detected (10%, range: 8–26), although the difference was not significant (Wilcoxon rank test, $P=0.6$).

Discussion

Our analysis highlights that for 38 years, beef-attributed outbreaks of salmonellosis have occurred regularly in the United States at a rate of approximately two per year, despite the fact that consumption of beef in the United States dropped 34% during the same time period [24]. Although roast beef and ground beef were implicated in a similar number of outbreaks during this period, we observed a striking change in the type of beef implicated over time. Most of the roast beef-attributed outbreaks occurred during 1973–1992, while nearly all ground beef-attributed outbreaks occurred during the last 10 years (2002–2011).

Roast beef-attributed outbreaks, caused by a variety of salmonella serotypes, were predominant during the 1970s and 1980s. During these years, the implicated roast beef was typically delicatessen-style, pre-cooked at a processing establishment. After several outbreak investigations in the 1970s revealed that the cooking temperature required to eliminate salmonella was often not achieved during processing [17, 25, 26], USDA-FSIS passed a series of regulations to ensure proper cooking of commercially pre-cooked roast beef [25–27], including an emergency change in 1977 requiring that roast beef be heated throughout to 145°F [25, 26]. USDA-FSIS amended this requirement in 1978 to cater to consumers' preference for roast beef that appeared rare or pink by providing alternative cooking times and temperatures that maintain the appearance of rare roast beef but eliminate salmonella [26]. After learning that humidity was not well-controlled during cooking, though moist heat is more effective than dry heat in killing salmonella, USDA-FSIS set further standards for production facilities, including guidance on humidity during cooking [27]. The roast beef-attributed outbreaks that occurred during the years immediately following passage of the new regulations resulted from failures to comply with regulations regarding roast beef processing and storage temperature [25, 28, 29]. However, the long-term positive impact of the regulations is clear. The last reported outbreak attributed to roast beef prepared in a commercial processing plant occurred in 1986.

Ground beef emerged as a predominant food vehicle in outbreaks reported during the 2000s. Several factors are hypothesized to have contributed to this emergence, including increased exposure to contaminated beef through changes in consumer and industry practices, and increased detection of outbreaks. Although average annual per capita consumption of ground beef declined from 33.7 pounds in 1980 to 27.6 pounds in 2006 [30], a population-based survey by USDA-FSIS and the U.S. Food and Drug Administration noted a significant increase in the percentage of persons who consumed undercooked ground beef during the 2000s [31]. In addition, the beef processing industry has become increasingly consolidated and complex. The percentage of beef produced by the four largest U.S. firms operating large meat processing plants increased from 26% in 1972 to 80% in 1997 [32]; large plants like these often mix and grind beef from multiple carcasses [33]. These circumstances provide an opportunity for contaminated beef from a single animal or supplier to be dispersed throughout a large batch of ground beef that is then widely distributed [33]. Variations in contamination of beef due to industry changes could have influenced the number of

outbreaks. Although studies and sampling programs have varied over time, one USDA survey in 1975 reported that only 0.4% of raw beef patties sampled were contaminated with salmonella [34], whereas USDA-FSIS reported an estimated 7.5% prevalence in ground beef samples in 1993–1994 [10] and <3% in the 2000s [9]. In addition, proactive decisions by USDA-FSIS in ground beef outbreak investigations might have also contributed to the increase. For example, in December 2007, USDA-FSIS issued a public health alert regarding ground beef products sold by a supermarket chain related to an outbreak of multidrug-resistant serotype Newport infections [35]. In July 2009, USDA-FSIS announced a recall of over 450000 pounds of ground beef related to an outbreak of infections with serotype Typhimurium DT104 infections [35]. In the December 6, 2012 Federal Register USDA-FSIS stated, “When NRTE poultry or meat products are associated with an illness outbreak and contain pathogens that are not considered adulterants, FSIS likely will consider the product linked to the illness outbreak to be adulterated under 21 U.S.C. 453(g)(3) or 21 U.S.C. 601(m)(3) because the product is “unsound, unhealthful, unwholesome, or otherwise unfit for human food” [14]. It is also likely that some multistate outbreaks were occurring before the 2000s but were not detected. CDC PulseNet, the national molecular subtyping network, identifies strains with similar pulsed-field gel electrophoresis (PFGE) patterns, assisting epidemiologists and other public health professionals in identifying and investigating widely dispersed outbreaks (<http://www.cdc.gov/pulsenet/index.html>) [36]. Although established in 1996, national participation in PulseNet for salmonella isolates was not reached until 2001, and the number of salmonella isolates subtyped increased almost 9-fold between 2001 and 2012 (*Kelley Hise, CDC, personal communication*), while the incidence of laboratory-confirmed salmonella infections in U.S. FoodNet sites remained unchanged [3]. Increased participation in PulseNet is the most likely reason that reports of multistate outbreaks, including those attributed to beef, have been increasing [4].

The percentage of outbreaks caused by the serotypes most commonly isolated from humans during the study period (Typhimurium and Enteritidis) [37] was relatively low for roast beef (12%) and other types of beef (24%) but 41% for ground beef and 33% for unknown type of beef. This, plus the finding that most ground beef-attributed outbreaks occurred in private homes, and that outbreaks of foodborne illness in private homes are generally less recognized than those at restaurants [4], raises the possibility that ground beef is responsible for an even greater proportion of salmonella illnesses than would be expected from an analysis of outbreak data [4].

Serotypes Newport and Typhimurium were the only serotypes identified in outbreaks caused by a multidrug-resistant strain. Multidrug-resistant strains of these serotypes emerged over the past three decades [38, 39]. Dairy cattle are an important source of both serotypes, particularly multidrug-resistant strains, and beef cattle might also be an important source of multidrug-resistant serotype Typhimurium strains [5, 38]. One study found that U.S. regions with the highest density of dairy cattle were also the regions where multidrug-resistant serotype Newport strains were isolated more frequently from ill persons [38]. The same relationship was observed between beef cattle density and multidrug-resistant serotype Typhimurium infections [38].

Dairy cattle at the end of their milk-producing careers are a source of leaner meat than beef cattle and are commonly used for ground beef [5]; they might be ill or stressed and consequently more likely to be shedding salmonella [40]. Further studies are also needed to understand how food animal production practices, including antimicrobial use, as well as animal age and health status might affect contamination of beef products.

This report has additional limitations. Even when outbreaks are reported, the vehicle or the contaminated ingredient is not always identified. Not all outbreaks are identified, and not all identified outbreaks are investigated or reported to CDC. Other outbreaks might have been due to beef, but beef might not be implicated if it was an ingredient, e.g., in beef stew. The contributing factors reported might be subjective observations because they are made at the time of the investigation and therefore might not have actually contributed to the outbreak. For example, investigators may have listed a restaurant or delicatessen as the point of preparation for contaminated roast beef inadequately cooked in a processing plant. The small proportion of outbreaks where information was available to pursue a traceback investigation (6%) limited our ability to assess factors contributing to contamination and amplification along the farm-to-table continuum. Finally, antimicrobial susceptibility testing was not assessed for isolates from most outbreaks, so those findings cannot be generalized. It is likely that strains were tested from certain outbreaks because resistance was suspected (e.g., outbreaks caused by serotype Newport) or because the outbreak was multistate. In addition, antimicrobial susceptibility testing methods and interpretations likely varied among laboratories.

In 1996, USDA-FSIS issued Pathogen Reduction; Hazard Analysis and Critical Control Point (PR/HACCP) Systems; Final Rule, which aimed to prevent foodborne illness caused by FSIS-regulated products [41]. The rule included salmonella performance standards for ground beef and encouraged the industry to implement measures to reduce the contamination of meat and poultry. The initial expansion of the use of pathogen reduction measures, such as thermal and chemical carcass decontamination, steam vacuuming, and steam pasteurization [42], likely contributed to the initial decreases in salmonella contamination of ground beef. However, in one recent study, salmonella, including multidrug-resistant strains, was found in 1.6% of lymph nodes sampled [43], while a second study found salmonella prevalence in lymph nodes destined for grinding varied (0%–88%) by origin of the cattle [44]. Salmonella has also been identified in peripheral lymph nodes collected from cattle carcasses at slaughter [43–45]. Interventions applied to the outside of beef carcasses would not likely affect salmonella in lymph nodes; peripheral lymph nodes are not generally removed before grinding [43–45]. Hypotheses about how salmonella is introduced into peripheral lymph nodes include dermal abrasions or insect bites [45]. Methods to decrease salmonella in peripheral lymph nodes, such as salmonella vaccination or pest management, might decrease contamination of ground beef [5, 43, 45, 46]. Currently, USDA-FSIS cultures randomly selected samples of beef products collected from plants through the PR/HACCP *Salmonella* Verification Sampling Program; if the number of positives exceeds the limit for ground beef (5 in a 53 sample set) [41], USDA-FSIS takes follow-up actions, which could include additional sampling or food safety assessments, and the establishment must take corrective action or cease production [41, 47]. USDA-FSIS has

proposed two changes to the *Salmonella* Verification Sampling Program: 1) testing additional samples of raw beef for salmonella, such as manufacturing and bench trimmings, and other components, and 2) increasing the volume of ground beef in each sample analysed (from 25 grams to 325 grams) [47]. These changes might improve the detection of salmonella and provide information about contamination of components.

Outbreaks attributed to beef, particularly ground beef, continue to occur despite current efforts. Although proper irradiation of food does not pose health risks [46] and the use of ionizing radiation to decrease pathogens in refrigerated and frozen uncooked meat has been permitted since 2000, irradiation of raw meat is still not accepted by most of the U.S. population [46]. Most ground beef-attributed outbreaks were from food prepared at home, where the risk of improper food handling and preparation might be higher than in a restaurant or delicatessen [48]. Studies indicating that one-third of Americans fail to use safe food-handling practices to prevent cross-contamination in the kitchen [49], and that almost twenty per cent of persons consuming ground beef say it was raw or undercooked [12], suggest that knowledge and practices of consumers and food handlers could be improved through sound risk communication and behavioral science to effect positive changes in food handling and cooking practices could help (for example: <http://www.cdc.gov/foodsafety/prevention.html>, <http://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education>). Consumers should continue to be vigilant about preparation of ground beef products and prevention of cross-contamination in the home. It is important to continue to reduce the contamination of meat and stronger measures are needed to prevent salmonella contamination of beef, including additional or novel methods of pathogen reduction during processing, reducing the prevalence of salmonella on the farm, and promoting antimicrobial stewardship. Enhancing surveillance for, investigation of, and traceback during outbreaks can decrease illnesses during an outbreak and final reporting of outbreaks to CDC can provide important scientific support of food safety interventions and policies to prevent future outbreaks. These prevention measures should also reduce the risk of foodborne illness caused by other pathogens and food vehicles.

Acknowledgments

We thank Robert V. Tauxe for early guidance in the analysis and for reviewing a draft of the manuscript, Daniel Engeljohn for early guidance in the analysis, Beth Karp for helpful comments, and others in the USDA Food Safety and Inspection Service for reviewing a draft of the manuscript. We also thank the state and local public health professionals who participated in the salmonella surveillance and outbreak investigations that made these analyses possible.

Financial support: This research received no specific grant from any funding agency, commercial or non-profit sectors.

References Cited

1. Scallan E, et al. Foodborne illness acquired in the United States--major pathogens. *Emerging Infectious Diseases*. 2011; 17:7–15. [PubMed: 21192848]
2. Centers for Disease Control and Prevention. Surveillance for foodborne disease outbreaks--United States, 2008. *MMWR Morbidity and Mortality Weekly Report*. 2011; 60:1197–1202. [PubMed: 21900873]
3. Centers for Disease Control and Prevention. Vital signs: Incidence and trends of infection with pathogens transmitted commonly through food--foodborne diseases active surveillance network, 10

- U.S., Sites, 1996–2010. MMWR Morbidity and Mortality Weekly Report. 2011; 60:749–755. [PubMed: 21659984]
4. Gould LH, et al. Surveillance for foodborne disease outbreaks - United States, 1998–2008. Morbidity and Mortality Weekly Report Surveillance Summaries. 2013; 62:1–34. [PubMed: 23804024]
 5. Centers for Disease Control and Prevention. Outbreak of multidrug-resistant *Salmonella* Newport-- United States, january–april 2002. MMWR Morbidity and Mortality Weekly Report. 2002; 51:545–548. [PubMed: 12118534]
 6. Dechet AM, et al. Outbreak of multidrug-resistant *Salmonella enterica* serotype Typhimurium definitive type 104 infection linked to commercial ground beef, Northeastern United States, 2003–2004. Clinical Infectious Diseases. 2006; 42:747–752. [PubMed: 16477547]
 7. McLaughlin JB, et al. Outbreak of multidrug-resistant *Salmonella* Typhimurium associated with ground beef served at a school potluck. Journal of Food Protection. 2006; 69:666–670. [PubMed: 16541701]
 8. Roels TH, et al. Incomplete sanitation of a meat grinder and ingestion of raw ground beef: Contributing factors to a large outbreak of *Salmonella* Typhimurium infection. Epidemiology and Infection. 1997; 119:127–134. [PubMed: 9363010]
 9. United States Department of Agriculture. Progress report on *Salmonella* and *Campylobacter* testing of raw meat and poultry products, 1998–2011. 2012. [www.fsis.usda.gov/wps/wcm/connect/f83a9981-4f9b-48da-a2a2-0b7effdc2edb/Progress_Report_Salmonella_Testing_1998-2011.pdf?MOD=AJPERES](http://www.fsis.usda.gov/wps/wcm/connect/f83a9981-4f9b-48da-a2a2-0b7effdc2edb/Progress_Report_Salmonella_Testing_1998-2011.pdf?MOD=AJPERES&www.fsis.usda.gov/wps/wcm/connect/f83a9981-4f9b-48da-a2a2-0b7effdc2edb/Progress_Report_Salmonella_Testing_1998-2011.pdf?MOD=AJPERES)
 10. United States Department of Agriculture. Nationwide federal plant raw ground beef microbiological survey, August 1993–March 1994. 1996. www.fsis.usda.gov/OPHS/baseline/rwgrbeef.pdf.
 11. United States Department of Agriculture. USDA cattle and beef statistics and information. 2013. www.ers.usda.gov/topics/animal-products/cattle-beef/statistics-information.aspx.
 12. Taylor EV, et al. Ground beef consumption patterns in the United States, FoodNet, 2006 through 2007. Journal of Food Protection. 2012; 75:341–346. [PubMed: 22289595]
 13. Anon. 511 F2d 331. United States: District Court for the District of Columbia; 1974. American Public Health Association et al appellants, v. Earl Butz, Secretary of Department of Agriculture, et al.
 14. United States Department of Agriculture. Federal Register. ed. 9. Washington, D.C: 2012. HACCP plan reassessment for not-ready-to-eat comminuted poultry products and related agency verification procedures. CFR Parts 417 [Docket No FSIS–2012–0007]. www.fsis.usda.gov/OPPDE/rdad/FRPubs/2012-0007.pdf
 15. Centers for Disease Control and Prevention. *Salmonella* Singapore --- New Orleans. MMWR Morbidity and Mortality Weekly Report. 1975; 24:397–398.
 16. Centers for Disease Control and Prevention. Salmonellae in precooked roasts of beef — New York. MMWR Morbidity and Mortality Weekly Report. 1978; 27:315.
 17. Shapiro R, et al. *Salmonella* Thompson associated with improper handling of roast beef at a restaurant in Sioux Falls, South Dakota. Journal of Food Protection. 1999; 62:118–122. [PubMed: 10030628]
 18. Eidson M, et al. Beef jerky gastroenteritis outbreaks. Journal of Environmental Health. 2000; 62:9–13.
 19. Centers for Disease Control and Prevention. Atlanta, GA: US Department of Health and Human Services, Centers for Disease Control and Prevention; 2012. National Antimicrobial Resistance Monitoring System — human isolates final report, 2011. www.cdc.gov/narms/pdf/2011-annual-report-narms-508c.pdf
 20. Fontaine RE, et al. Raw hamburger: An interstate common source of human salmonellosis. American Journal of Epidemiology. 1978; 107:36–45. [PubMed: 623088]
 21. Spika JS, et al. Chloramphenicol-resistant *Salmonella* Newport traced through hamburger to dairy farms. A major persisting source of human salmonellosis in California. New England Journal of Medicine. 1987; 316:565–570.

22. Centers for Disease Control and Prevention. Multistate outbreak of *Salmonella* Newport transmitted by precooked roasts of beef. MMWR Morbidity and Mortality Weekly Report. 1977; 26:277–288.
23. Talbot EA, Gagnon ER, Greenblatt J. Common ground for the control of multidrug-resistant *Salmonella* in ground beef. Clinical Infectious Diseases. 2006; 42:1455–1462. [PubMed: 16619160]
24. United States Department of Agriculture. USDA agricultural baseline projections, baseline-related historical data. 2013. www.ers.usda.gov/topics/farm-economy/agricultural-baseline-projections/baseline-related-historical-data.aspx
25. Centers for Disease Control and Prevention. Multistate outbreak of salmonellosis caused by precooked roast beef. MMWR Morbidity and Mortality Weekly Report. 1981; 30:391–392. [PubMed: 6790931]
26. Parham, GL. Salmonellae in cooked beef products. In: Snyenbos, GH., editor. Proceedings of the International Symposium on *Salmonella*; New Orleans, Louisiana. American Association of Avian Pathologists, Inc. University of Pennsylvania; 1984. p. 275-280.
27. United States Department of Agriculture. Federal Register. ed. 9. Vol. 64. Washington, D.C: 1999. Performance standards for the production of certain meat and poultry products; final rule; p. 732-749. CFR Parts 301, 303, et al. <http://www.fsis.usda.gov/OPPDE/rdad/FRPubs/95-033F.htm>
28. Centers for Disease Control and Prevention. Multiple outbreaks of salmonellosis associated with precooked roast beef--Pennsylvania, New York, Vermont. MMWR Morbidity and Mortality Weekly Report. 1981; 30:569–570. [PubMed: 6795438]
29. Spitalny KC, Okowitz EN, Vogt RL. Salmonellosis outbreak at a Vermont hospital. Southern Medical Journal. 1984; 77:168–172. [PubMed: 6701583]
30. National Cattleman's Beef Association. Average annual per capita consumption beef cuts and ground beef. 2012 <http://www.beefusa.org/CMDocs/BeefUSA/Resources/Statistics/averageannualpercapitaconsumptionbeefcutsandgroundbeef559.pdf>.
31. Fein SB, et al. Trends in U.S. consumers' safe handling and consumption of food and their risk perceptions, 1988 through 2010. Journal of Food Protection. 2011; 74:1513–1523. [PubMed: 21902921]
32. Kandel W, Parrado EA. Restructuring of the US meat processing industry and new Hispanic migrant destinations. Population and Development Review. 2005; 31:447–471.
33. Armstrong GL, Hollingsworth J, Morris JG Jr. Emerging foodborne pathogens: *Escherichia coli* O157:H7 as a model of entry of a new pathogen into the food supply of the developed world. Epidemiologic Reviews. 1996; 18:29–51. [PubMed: 8877329]
34. Surkiewicz BF, et al. Bacteriological survey of raw beef patties produced at establishments under federal inspection. Applied Microbiology. 1975; 29:331–334. [PubMed: 1090254]
35. United States Department of Agriculture. Recall case archive. www.fsis.usda.gov/wps/portal/fsis/topics/recalls-and-public-health-alerts/recall-case-archive.
36. Ribot EM, et al. Standardization of pulsed-field gel electrophoresis protocols for the subtyping of *Escherichia coli* O157:H7, *Salmonella* and *Shigella* for PulseNet. Foodborne Pathogens and Disease. 2006; 3:59–67. [PubMed: 16602980]
37. Centers for Disease Control and Prevention. Atlanta, GA: US Department of Health and Human Services, CDC; 2013. National *Salmonella* surveillance annual report, 2011. www.cdc.gov/ncezid/dfwed/pdfs/salmonella-annual-report-2011-508c.pdf
38. Greene SK, et al. Distribution of multidrug-resistant human isolates of MDR-ACSSuT *Salmonella* Typhimurium and MDR-AmpC *Salmonella* Newport in the United States, 2003–2005. Foodborne Pathogens and Disease. 2008; 5:669–680. [PubMed: 18851677]
39. Varma JK, et al. Antimicrobial-resistant nontyphoidal *Salmonella* is associated with excess bloodstream infections and hospitalizations. Journal of Infectious Diseases. 2005; 191:554–561. [PubMed: 15655779]
40. Call DR, Davis MA, Sawant AA. Antimicrobial resistance in beef and dairy cattle production. Animal Health Research Reviews / Conference of Research Workers in Animal Diseases. 2008; 9:159–167. [PubMed: 18983724]

41. United States Department of Agriculture. Pathogen reduction; hazard analysis and critical control point (HACCP) systems; final rule; Title 9 Federal Register Parts 310, 381: United States Department of Agriculture, Food Safety and Inspection Service. Code of Federal Regulations. 1996. p. 38805-38989. www.fsis.usda.gov/OPPDE/rdad/FRPubs/93-016F.htm.
42. Stopforth J, Sofos J. Recent advances in pre-and post-slaughter intervention strategies for control of meat contamination. *Advances in Microbial Food Safety*, ACS Symposium: ACS Publications. 2006:66–86.
43. Brichta-Harhay DM, et al. Microbiological analysis of bovine lymph nodes for the detection of *Salmonella enterica*. *Journal of Food Protection*. 2012; 75:854–858. [PubMed: 22564933]
44. Haneklaus AN, et al. *Salmonella* prevalence in bovine lymph nodes differs among feedyards. *Journal Food Protection*. 2012; 75:1131–1133.
45. Gragg SE, et al. Cross-sectional study examining *Salmonella enterica* carriage in subiliac lymph nodes of cull and feedlot cattle at harvest. *Foodborne Pathogens and Disease*. 2013; 10:368–374. [PubMed: 23566273]
46. Frenzen PD, et al. Consumer acceptance of irradiated meat and poultry in the United States. *Journal of Food Protection*. 2001; 64:2020–2026. [PubMed: 11770633]
47. United States Department of Agriculture. Changes to the *Salmonella* verification sampling program: Analysis of raw beef for shiga toxin-producing *Escherichia coli* and *Salmonella*; request for comment. *Federal Register*. 2013; 78:53017–53020. [Docket No FSIS–2013–0038].
48. Centers for Disease Control and Prevention. Use of a self-assessment questionnaire for food safety education in the home kitchen --- Los Angeles county, California, 2006–2008. *MMWR Morbidity and Mortality Weekly Report*. 2010; 59:1098–1101. [PubMed: 20814405]
49. Altekruze SF, et al. Consumer knowledge of foodborne microbial hazards and food-handling practices. *Journal of Food Protection*. 1996; 59:287–294. [PubMed: 10463448]

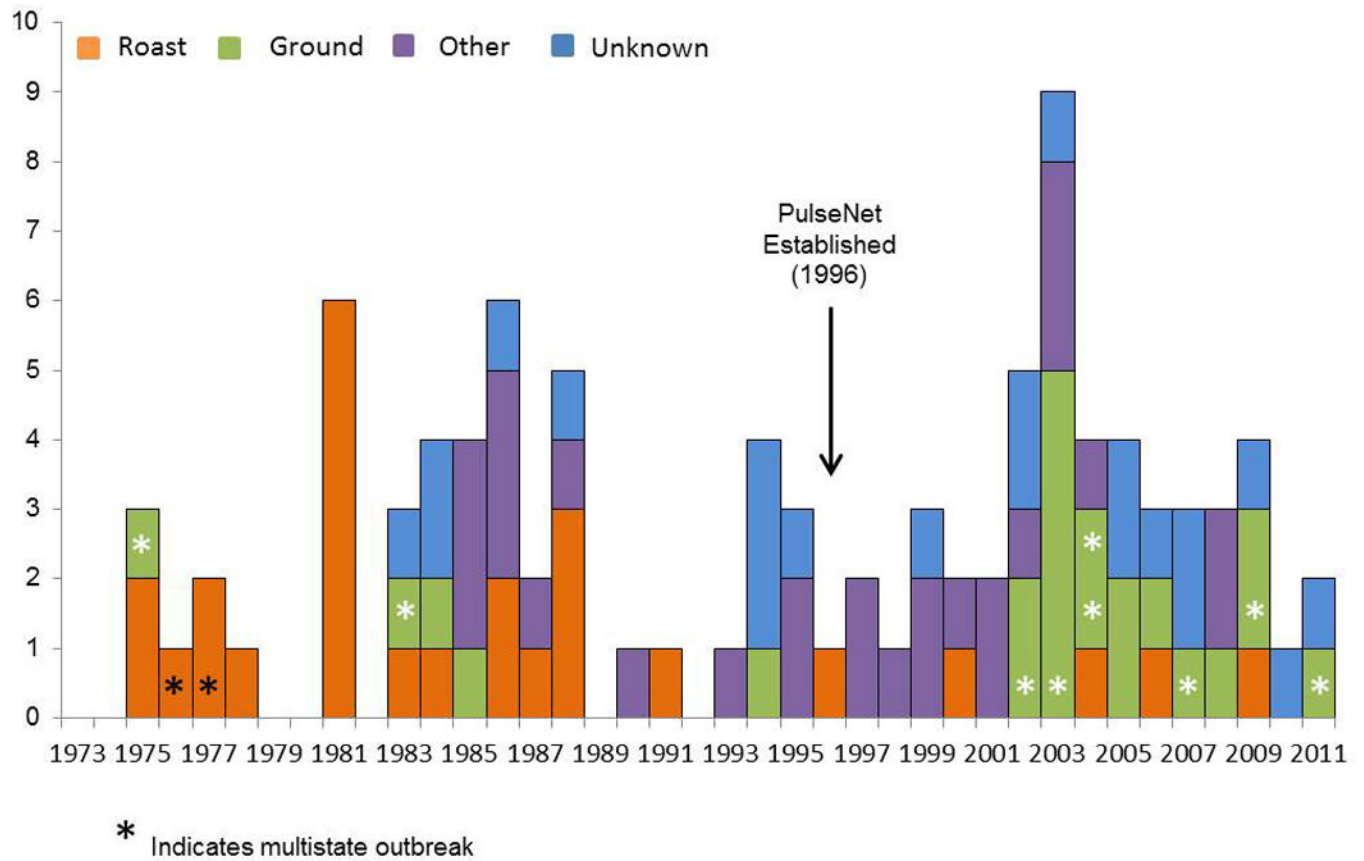


Figure 1.
Outbreaks of *Salmonella enterica* infections where beef was the implicated vehicle, by type and year, United States, 1973–2011.

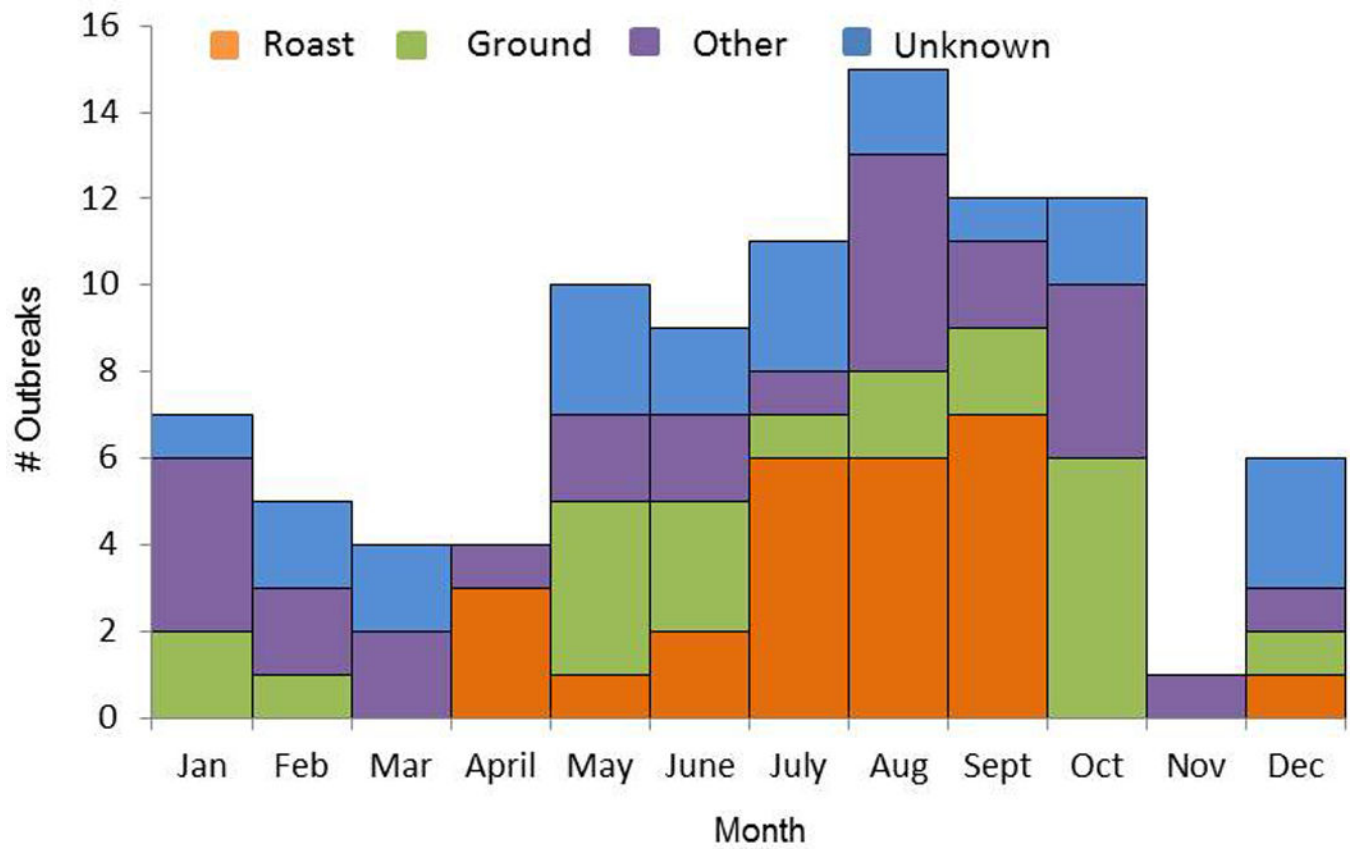


Figure 2.
Distribution of beef-attributed outbreaks of *Salmonella enterica* infections, by type and month, United States, 1973–2011.

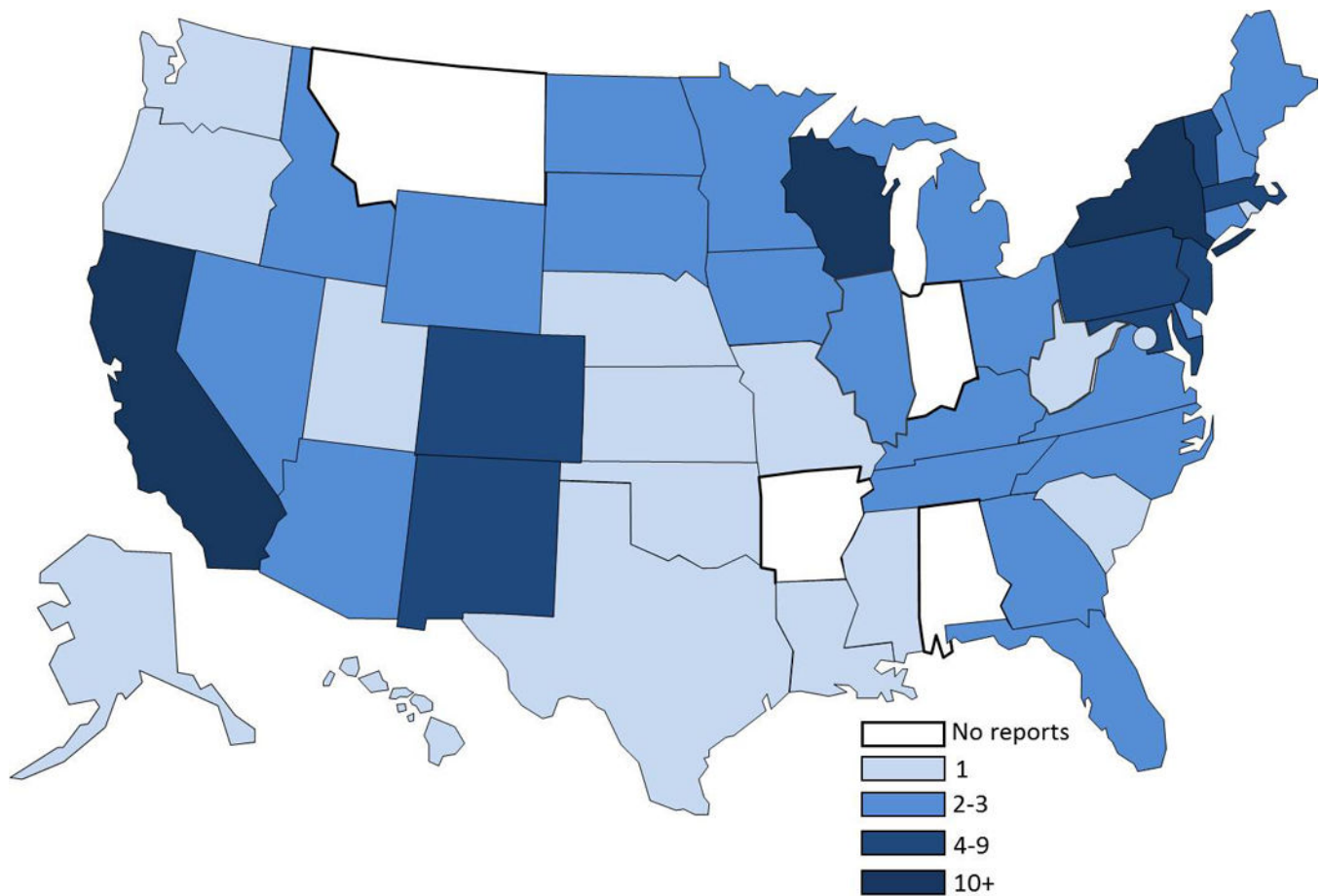


Figure 3.

Number of *Salmonella enterica* outbreaks where beef was the implicated vehicle by state, 1973–2011. States were involved in 85 single-state and 11 multistate outbreaks. Multistate outbreaks are counted as an outbreak for each state that reported a case¹.

¹States involved in multistate outbreaks included: Arizona (2 multistate outbreaks), California (2), Colorado (3), Connecticut (3), Delaware (1), Idaho (2), Illinois (1), Iowa (1), Kansas (1), Kentucky (1), Maine (1), Maryland (2), Massachusetts (2), Michigan (2), Nebraska (1), Nevada (2), New Hampshire (1), New Jersey (5), New Mexico (2), New York (5), Pennsylvania (5), Rhode Island (1), South Dakota (2), Tennessee (2), Texas (1), Utah (1), Vermont (1), Virginia (1), Wisconsin (1), Wyoming (2), Washington, D.C. (1).

Table 1

Characteristics of outbreaks of *Salmonella enterica* infections where beef was the implicated food vehicle, by beef type, United States, 1973–2011.

Characteristic	N	Roast n (%)	Ground n (%)	Other Types ¹ n (%)	Unknown n (%)
Outbreaks	96	26 (27)	22 (23)	30 (31)	18 (19)
Illnesses	3684	1381 (37)	916 (25)	911 (25)	476 (13)
Median per outbreak (range)	29 (2–200)	47 (4–200)	36 (3–158)	15 (2–130)	19 (3–75)
Hospitalizations	318	73 (23)	141 (44)	72 (23)	32 (10)
Median per outbreak (range)	2 (0–22)	2 (0–19)	5 (0–22)	0 (0–20)	2 (0–6)
Deaths	5	1 (20)	4 (80)	0 (0)	0 (0)
Median per outbreak (range)	0 (0–2)	0 (0–1)	0 (0–2)	0 (0)	0 (0)
Female ²	558 (52)	183 (49)	180 (58)	154 (51)	41 (48)
Aged 20–49 years ³	500 (50)	199 (53)	137 (44)	107 (49)	57 (66)
Setting of food preparation ⁴					
Restaurant or delicatessen	35 (40)	10 (42)	4 (21)	16 (55)	5 (29)
Private home	25 (28)	1 (4)	12 (63)	4 (14)	8 (47)
Processing plant	15 (17)	9 (38)	0 (0)	5 (17)	1 (6)
Other or unspecified ⁵	34 (39)	8 (33)	10 (53)	11 (38)	5 (29)
Contributing factors ⁶					
Improper food handling	21 (67)	2 (50)	8 (47)	8 (50)	3 (33)
Environmental contamination	19 (61)	0 (0)	10 (59)	6 (38)	3 (33)
Cross-contamination	14 (45)	3 (75)	2 (12)	5 (31)	4 (44)
Worker contamination	7 (23)	1 (25)	2 (12)	2 (13)	2 (22)
Other contamination	2 (6)	0 (0)	1 (6)	1 (6)	0 (0)

¹ Eight types of beef were reported: steak (8 outbreaks); brisket and jerky (7 outbreaks each); barbecued (4); barbacoa, beef blood, ribs, tripe (1 each).

² Gender data collected since 1998; information available for 36 (78%) outbreaks

³ Age data collected since 1998; age distribution available for 33 (72%) outbreaks

⁴ Not mutually exclusive; 88 (92%) outbreak reports included data on at least one food preparation setting (24 roast beef, 19 ground beef, 29 other type, 17 unknown beef type); 69 outbreaks reported only one setting (20 roast beef, 12 ground beef, 22 other type, and 15 unknown beef type)

Author Manuscript

Author Manuscript

Author Manuscript

Author Manuscript

5 Other or unspecified setting: Unspecified (11 reports); school (5); cafeteria or hall, caterer, supermarket or grocery store (4 each); church or temple, fair, festival, or other temporary mobile food service (2 each); picnic, field dressed cow (1 each)

6 Not mutually exclusive; data on contributing factors were collected beginning in 1998. At least one contributing factor was reported for 31 (67%) of the 46 outbreaks (4 roast beef, 17 ground beef, 16 other, and 9 unknown) reported during 1998 to 2011.

Table 2

Characteristics of outbreaks of *Salmonella enterica* infections in which beef was the implicated vehicle, by serotype, United States, 1973–2011.

Characteristic	Typhimurium n (%)	Newport n (%)	Enteritidis n (%)	Other serotypes ¹ n (%)	Multiple serotypes n (%)	Serotype not reported ² n (%)	Total N
Outbreaks	16 (17)	15 (16)	9 (9)	43 (45)	6 (6)	7 (7)	96
Illnesses	614 (17)	656 (18)	292 (8)	1695 (46)	347 (9)	80 (2)	3684
Hospitalizations	58 (18)	93 (29)	32 (10)	123 (39)	8 (3)	4 (1)	318
Beef type							
Roast	2 (8)	2 (8)	1 (4)	16 (62)	4 (15)	1 (4)	26
Ground	6 (27)	7 (32)	3 (14)	6 (27)	0 (0)	0 (0)	22
Other	3 (10)	3 (10)	4 (13)	14 (47)	1 (3)	5 (17)	30
Unknown	5 (28)	3 (17)	1 (5)	7 (39)	1 (5)	1 (5)	18

¹The other serotypes were Heidelberg, Montevideo, Saintpaul (4 outbreaks each); Berta, Infantis, Thompson (3 outbreaks each); Agona, Anatum, Chester, Hadar, Reading (2 outbreaks each); Agama, Bovismorbificans, Braenderup, Cerro, Derby, Hartford, Kiambu, Ohio, Oranienburg, Singapore, Schwarzengrund, Senftenberg (one outbreak each).

²Serogroup was reported in three outbreaks with no serotype reported, including Group B (2 outbreaks) and Group C1 (1 outbreak).