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Relationship between home food-handling practices and sporadic salmonellosis in adults in Louisiana, United States

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SUMMARY

Salmonellosis is the leading cause of death caused by foodborne bacterial pathogens in the United States. Approximately 90% of salmonella infections are sporadic, but most of what is known about salmonellosis has come from outbreak investigations. We studied the risk for sporadic salmonellosis among 115 persons aged $\geqslant$ 15 years reported to the Louisiana Office of Public Health during May 1998–April 1999, compared with 115 age-matched controls. Significantly more case-patients than controls had chronic underlying medical conditions [adjusted odds ratio (aOR) = 4·3; 95% confidence interval (CI) = 2·2–8·7]. Although reported consumption of specific food items likely to contain salmonella was not associated with illness, inconsistent handwashing between preparation of meat and non-meat items was associated with illness (aOR = 8·3; CI = 1·1–61·8). Enhanced measures to provide a consistently safe food supply and promote safer food preparation in households will depend on prevention of sporadic salmonellosis.

INTRODUCTION

Salmonellosis is the leading cause of hospitalizations and deaths caused by known foodborne bacterial pathogens in the United States each year [1]. The reported incidence of non-typhoid salmonella infections increased steadily worldwide between 1985 and 1995 [2] and continued to increase in the United States in recent years as found through active surveillance in selected sites [3]. In 1998, a total of 34608 culture-confirmed cases were reported in the United States. However, reported cases could represent < 5% of the actual incidence of human salmonellosis [4]. The annual direct and indirect medical and other costs to society of salmonellosis could exceed $4 billion in the United States [5, 6].

Although most of what is known about the acquisition of salmonellosis comes from investigations of outbreaks, approximately 90% of cases are sporadic [1]. Most recognized outbreaks of salmonellosis are caused by a common source, usually certain food items. However, few studies have examined risk factors for sporadic salmonellosis, and most have concentrated on specific common serotypes, mainly *Salmonella* Typhimurium and *S.* Enteritidis [7, 8] and on consumption of certain food items such as egg products [7, 9]. Meats and other food items are frequently contaminated with salmonella at the time of consumer purchase. Although these items can be

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the source of salmonella organisms causing sporadic illness, many more persons are exposed than become ill. The differences between persons who develop salmonellosis and those who eat the same contaminated food item and do not become ill are unclear. Whether exposure results in illness can depend on non-food-related factors, e.g. food-handling practices, factors in the household environment, demographic features, and recreational activities.

Efforts are increasing to use primary prevention to make the US food supply safer at the source level. One example is the hazard analysis and critical control points (HACCP) strategy of the Food Safety and Inspection Service, an agency of the US Department of Agriculture (USDA) [10], which promotes enhanced inspection procedures at production plants to reduce the risk for contamination of animal products. However, until the goal of a consistently safer food supply is reached, the risk for sporadic salmonellosis from food will continue. Therefore, we should increase our understanding of food-handling practices that influence the likelihood of acquiring salmonella.

In 1998, a total of 864 cases (20·0/100 000) of salmonellosis was reported in Louisiana, making it the most frequently reported cause of gastrointestinal illness in the state; none of these cases was identified as outbreak-related. We conducted a case-control study of sporadic salmonella infections in older adolescents and adults, in order to understand the mechanisms of transmission for salmonellosis outside of outbreaks. We focussed on sporadic salmonellosis, so that interventions could be designed that address risk factors at the production and consumer level.

METHODS

Informed consent was obtained from all participating patients and controls. The study was exempt from humans subject review by CDC's Internal Review Boards as part of ongoing and routine surveillance activities.

Reporting of salmonellosis to the Louisiana Office of Public Health is mandatory and all related isolates of salmonella must be sent to the state laboratory for serotyping. For our study, cases were identified through routine reporting from infection control practitioners, local health units, and the state laboratory. Letters encouraging prompt reporting of positive isolates were sent to the reporting sources.

A case-patient was defined as a Louisiana resident aged $\geqslant 15$ years with diarrhoea from whom salmonella was isolated from stool and who was not identified as part of a recognized outbreak. If specimens from > 1 case-patient were the same salmonella subtype, chromosomal DNA restriction patterns, generated by *Xba*I restriction digests, were analysed by pulsed-field gel electrophoresis (PFGE) [11]. Case-patients were excluded from the study if they could not be interviewed within 6 weeks of their date of onset of symptoms. Case-patients who reported a date of onset from 1 May 1998 to 30 April 1999, were enrolled.

One control was selected for each case. Controls were randomly selected using a listing of residential telephone numbers for Louisiana. Within each randomly selected residence, the person aged $\geqslant 15$ years with a date of birth closest to the interview date was asked to participate. Controls with symptoms of diarrhoea and fever in the 2 weeks before or after the date of onset of the case were excluded. Controls were interviewed within 10 days of the case-patient interview; if this was not possible, the case was excluded from the study.

All interviews were conducted by telephone using a standard questionnaire. Case-patients were excluded and potential controls were replaced after nine failed attempts to contact them at different times of the day and different days of the week.

Case-patients were asked about exposures in the 7 days before the date of onset of infection; controls were asked about exposures for the same period as their matched case to reduce possible bias caused by changes in eating habits and general behaviours from seasonal differences. The questionnaire addressed four main areas: (1) demographics (age, sex, race, underlying medical conditions and education) and health insurance status; (2) food consumption exposures, including meat and non-meat items and restaurant exposures; (3) food preparation habits, including hand washing between meat and non-meat items and type of cooking utensils used; and (4) household environment and recreational exposures, including exposure to domestic animals, persons in diapers, previous use of antacids and antibiotics, and recreational water activities. Questions on food preparation habits were asked separately for the person in the household who prepared most of the meals (defined as the primary food preparer) and for case-patients and controls who only occasionally prepared foods (defined as occasional food preparers). Responses for food consumption and food preparation habits were categorized by the likelihood of their occurrence and when analysed, were grouped into two categories: 'likely' (always or very likely and often or likely) and 'unlikely' (never and rarely or not likely).

Univariate analysis of exposures were analysed with Epi-Info 6 (Centers for Disease Control and Prevention, Atlanta, GA, USA). Odds ratios (ORs) were calculated using both matched and unmatched methods. Because ORs for matched case-control pairs did not differ substantially from unmatched ORs, unmatched results are presented [12]. Age and the presence of pre-existing medical conditions were strongly associated with case status. Thus we adjusted for age (in 10-year intervals) and for presence of underlying illness using the Mantel–Haenszel procedure. Case-patients who had any kidney, liver, or heart condition in the 6 months before onset of illness were defined as having underlying medical illness. Selected risk factors for salmonella infection were evaluated in a logistic regression model using SAS 6.12 (SAS Institute Inc., Cary, NC, USA).

RESULTS

During May 1998–April 1999, a total of 888 cases of sporadic salmonellosis was reported to the Louisiana Office of Public Health. Of these, 324 case-patients were aged ⩾ 15 years and 166 (51 %) were potentially eligible for participation in our study. Most of the 158 non-eligible participants did not meet the inclusion criteria of positive salmonella isolates from stool or of being reported within 6 weeks of onset of symptoms. Of the 166 eligible participants, 115 (69 %) case-patients were included in the study. Among the 51 cases not included, 18 could not be contacted within 9 attempts, 15 had no working telephone number, 7 were not mentally able to complete the interview, 4 were excluded because no control could be contacted within 10 days of the case, 3 refused participation, 3 had died, and 1 had no reason recorded for exclusion. The median time from onset of illness to interview of the case-patient was 27 days (range: 5–42 days). All case-patients reported symptoms of diarrhoea with a median maximum number of stools of 10 per 24 h (range: 2–50); 83 (72 %) reported fever with a median maximum temperature of 102·0 F (range: 99·0–106·0).

One hundred and ninety households were called to enrol 115 controls. Of the remaining 75 households, 52 refused to participate, 17 could not be reached within 9 attempts, 5 potential controls reported fever and diarrhoea, and 1 control was not mentally able to be interviewed.

The sex and race distribution of case-patients and controls was similar; 64 % of case-patients and 61 % of controls were female; 75 % of case-patients and 74 % of controls were white. Case-patients tended to be older than controls. The median age of enrolled case-patients was 48 years (range: 15–88 years); the median age of controls was 42 years (range: 15–80 years). Twenty-two percent of case-patients, compared with 8 % of controls, were aged ⩾ 70 years (Table 1). Case-patients were less likely than controls to have private health insurance (56 *vs.* 71 %); they were less likely to have higher formal education than controls (24 % compared to 37 % graduated from college or graduate school). Case-patients were significantly more likely to have a pre-existing medical condition than controls [OR = 4·3; 95 % confidence interval (CI) = 2·2–8·7] (Table 2) particularly any liver, kidney, or heart condition (OR = 7·3, 6·7, 5·3, respectively), which was defined as underlying illness (OR = 5·6). PFGE testing for salmonella isolates, when ⩾ 2 isolates were of the same serotype, indicated that 4 of 8 specimens of *S.* Enteritidis had the same pattern. Otherwise, all isolates had unique patterns.

Consumption of specific food items in the 7 days before illness onset in case-patients was not associated with an increased risk for illness (Table 3); in fact, consumption of certain food items appeared to have a 'protective' effect being negatively associated with illness. Preparation of food items either as a primary or occasional food preparer (data not shown) was also not associated with illness. Among types of restaurants to which subjects were exposed in the 7 days before illness onset in case-patients, only food consumption in a work or school cafeteria indicated a borderline association with illness [adjusted (a)OR = 2·0]. In general, case-patients were slightly less likely than controls to have eaten in restaurants during the 7 days before onset of illness (aOR = 0·8; 95 % CI = 0·4–1·7) (restaurants in all price categories).

Adjusting for age group and illness status, case-patients reported less often than controls that they were either the primary food preparer in the household (aOR = 0·5) or an occasional food preparer (aOR = 0·3) (Table 4). However, among case-patients and controls who prepared foods either as the primary or occasional food preparer, we did observe an association that explained many of these cases of sporadic salmonellosis. Significantly more case-patients in this group reported 'never' or 'rarely'

Table 1. *Demographic and socio-economic characteristics of case-patients with salmonella infection and controls**

Characteristics	No. of cases	No. of controls	OR†	95% CI‡
Sex				
Female	73	71	1·1	0·6–1·9
Male	42	44	Ref.§	
Age group (years)				
15–19	10	7	Ref.§	
20–29	12	16	0·5	0·1–2·1
30–39	19	31	0·4	0·1–1·5
40–49	18	24	0·5	0·1–1·9
50–59	17	18	0·7	0·2–2·5
60–69	14	10	1·0	0·2–4·2
⩾ 70	25	9	1·9	0·5–7·9
Race				
Caucasian	86	84	Ref.§	
African American	24	25	0·9	0·5–1·9
Other	5	4	1·2	0·3–5·6
Medical insurance				
HMO‖/PPO¶	64	82	Ref.§	
Medicare/Medicaid	36	18	2·6	1·3–5·2
Other insurance	11	12	1·2	0·5–3·1
No insurance	3	3	1·0	0·2–6·3
Education				
No high school diploma	33	18	2·8	1·2–6·2
High school graduate	54	55	1·5	0·8–2·8
College graduate	28	42	Ref.§	
Total	115	115		

* Missing data are excluded; † odds ratio; ‡ confidence interval; § reference group for odds ratios; ‖ health maintenance organization; ¶ preferred provider organization.

Table 2. *Association between illness with salmonella and pre-existing medical condition or therapy among case-patients and controls*

Medical condition* or therapy†	No. of cases	No. of controls	Adjusted OR‡	95% CI§
Pre-existing medical condition	50	16	4·3	2·2–8·7
Liver	7	1	7·3	0·8–63·7
Kidney	7	1	6·7	0·7–60·6
Heart	27	5	5·3	1·8–15·2
Irritable bowel syndrome	14	6	2·4	0·9–6·5
Ulcer	14	7	2·1	0·8–5·4
Sickle cell	0	1	NC‖	
Kidney, liver, heart conditions combined¶	35	7	5·6	2·3–13·5
Antacids	58	50	1·4	0·8–2·3
Antibiotics	27	23	1·2	0·6–2·3

* In 6 months before onset of illness; † in 4 weeks before onset of illness; ‡ odds ratio adjusted for age group; § confidence interval; ‖ not calculated due to zero subjects in cells; ¶ defined as 'underlying illness'.

washing their hands every time between preparation of meat and non-meat items (aOR = 8·3). When asked about the type of cutting surface used for preparation of meat and non-meat items, slightly more case-patients reported using wooden cutting boards (aOR = 1·3); however, case-patients were no

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Table 3. *Association between illness with salmonella and consumption of selected food items and exposure to selected types of restaurants among 115 case-patients and 115 controls*

	Number exposed			
Exposure*	Cases	Controls	Adjusted OR†	95% CI‡
Consumption of food items				
Ground pork	12	13	1·3	0·5–3·2
Eggs	63	68	0·8	0·5–1·4
Sausage	42	48	0·8	0·5–1·5
Ground beef	73	92	0·4	0·2–0·8
Vegetables	66	92	0·4	0·2–0·8
Chicken	94	107	0·3	0·1–0·8
Fruits	72	99	0·2	0·1–0·5
Type of restaurant				
Cafeteria (work/school)	33	25	2·0	1·0–3·8
Fast food chicken	30	34	0·9	0·5–1·7
Fast food hamburger	49	62	0·6	0·3–1·1
Deli shops	17	38	0·5	0·2–0·9
Restaurant category				
Cheap (< $6)§	75	91	0·5	0·3–1·1
Inexpensive ($6–< $15)	56	84	0·4	0·2–0·8
Moderate ($15–< $25)	16	32	0·7	0·3–1·4
Expensive (⩾ $25)	2	7	0·5	0·1–3·1

* In 7 days before onset of illness; † odds ratio by age group and chronic illness; ‡ confidence interval; § price per meal.

Table 4. *Association between illness with salmonella and food-handling practices and types of cooking utensils used by 115 case-patients and 115 controls*

	Number exposed			
Risk factors*	Cases	Controls	Adjusted OR†	95% CI‡
Food preparer				
Interviewee prepared no foods	28	16	Ref.**	
Interviewee was primary preparer	70	74	0·5	0·3–1·1
Interviewee was occasional preparer	12	22	0·3	0·1–0·9
Hand-washing practices§‖				
Often/always or never prepares meats	68	95	Ref.**	
Never/rarely	13	1	8·3	1·1–61·8
Cutting surface				
Wood *vs.* glass/plastic/PVC or never prepares meats	40	29	1·3	0·6–2·5
Same for meat and non-meat items *vs.* different surface	63	63	0·9	0·5–1·5
Not cleaned each time between meat and non-meat items *vs.* cleaned each time	2	1	3·7	0·3–44·9
Cleaned with water *vs.* soap/disinfectant/bleach/other¶	8	4	1·4	0·4–5·9
Hand-washing *vs.* dishwasher**	60	44	1·5	0·8–2·7

* In 7 days before onset of illness; † odds ratio adjusted by age group and underlying sick status; ‡ confidence interval; § between preparation of meat and non-meat items; ‖ interviewees who never prepared food were excluded; ¶ includes dishwasher; ** reference group for calculation of odds ratios.

Table 5. *Association between illness with salmonella and selected household and recreational exposures*

Exposure*	Number exposed		Adjusted OR†	95% CI‡
	Cases	Controls		
Elderly persons in diapers in household	3	1	6·7	0·3–151·6
Household members with diarrhoea	13	11	1·4	0·5–3·6
Household members diagnosed with salmonella	2	0	NC‖	
Travel outside US	1	2	1·0	0·1–8·3
Household animals				
Ownership	72	77	0·9	0·5–1·6
Physical contact	68	75	0·8	0·5–1·6
Contact with open body of water§	9	19	0·5	0·2–1·1
Contact with young children¶	26	45	0·5	0·3–1·0
Swimming	5	16	0·4	0·1–1·0

* In 7 days before onset of illness; † odds ratio adjusted by age group and chronic illness; ‡ 95% confidence interval; § e.g. lakes, rivers, swamps; ‖ not calculated due to zero subjects in cells; ¶ infants or non-toilet trained children and/or children in day care centres.

more likely than controls to use the same cutting surface for the preparation of meat and non-meat items. Although not statistically significant, not cleaning the cutting surface each time between preparation of meat and non-meat items and cleaning of the cutting surface with water only instead of use of soap, disinfectant, bleach, or a dishwasher had elevated ORs (aOR = 3·7 and 1·4, respectively). Case-patients were slightly more likely to wash dishes by hand than with a dishwasher (aOR = 1·5), but this difference did not reach statistical significance.

To test for independence of inconsistent hand washing and food consumption in a cafeteria as positively associated risk factors for salmonella infection and of selected negatively associated factors, we entered hand washing of the primary food preparer; cafeteria use; and consumption of eggs, fruits, chicken, ground beef, and vegetables in a logistic regression model. After controlling for underlying medical condition and age, we found inconsistent hand washing of primary food preparers (aOR = 4·3) and consumption of food in a cafeteria (aOR = 2·6) to be independently and strongly associated with infection; all protective factors remained independently negatively associated with infection (data not shown).

When asked about possible risk factors in the household environment, case-patients reported more often than controls that diaper-using elderly persons resided in the household (aOR = 6·7), and that other persons in the household had been ill with diarrhoea (aOR = 1·4) in the 7 days before the case-patient's onset of illness. However, the number of persons reporting these exposures was very small. Case-patients were no more likely than controls to have had or touched domestic or zoo animals (aOR = 0·9 and 0·8, respectively), with the exception of reptiles (aOR = 6·1; 95% CI = 0·7–55·2 for having a reptile in the household). Case-patients were less likely to have participated in any recreational water activities, e.g. swimming (aOR = 0·4; Table 5).

DISCUSSION

We examined and identified risk factors not commonly associated with outbreak-related salmonellosis but possibly contributing to sporadic disease that causes the majority of salmonella infections. The most strongly associated risk factor was lack of regular hand-washing between preparation of meat and non-meat items. Cross-contamination experiments have demonstrated that salmonella from raw chicken can easily be transferred to hands and cutting board surfaces, from which bacteria can be cultured several hours later [13] – potentially cross-contaminating other products. A previous study reported an association between sporadic *S.* Newport infection and the handling of raw ground or cut beef rather than consumption of meat items [14]. A risk factor study of sporadic infection in 23 patients with *Escherichia coli* O157:H7 infections over 2 months reported that adequate hand-washing after handling of raw ground beef by food preparers could prevent 34% of infections [15]. This study also reported an association with inadequate washing of work surfaces and

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infection after handling of (contaminated) raw ground beef.

We documented only small, statistically non-significant risks associated with the type of cutting board used to prepare food. The benefits of different types of cutting surfaces are not clear. Experimental studies indicated that wooden cutting boards inoculated with bacteria are more retentive of viable bacteria than plastic boards [16]. Although this might increase the number of bacteria in a wooden board after meat is cut, the likelihood of the bacteria contaminating other foods could decrease. Bacteria can become completely absorbed by wood [17], whereas plastic boards with knife scars are more difficult to clean and more bacteria can be recovered from them [18]. Our study did not provide evidence that either type of cutting surface was safer, although the cleaning method could affect disease risk.

A nationwide telephone survey of home food consumption and preparation behaviours reported a higher rate than our study of not cleaning cutting boards between meat and non-meat items [19]. Unlike our survey, participants were not asked about the frequency of such behaviour, which could give more realistic estimates. A substantial proportion of participants reported unsafe food consumption and hygiene practices and a better understanding of the mechanisms of cross-contamination was associated with safe food-handling practices [20]. The survey also did not ask about disease status, which avoided reporting or recall bias and could explain some of the differences. In addition, consumer awareness might have improved since publication of the survey, which was conducted in 1992. If failure to wash cutting boards between meat and non-meat items is a risk for acquiring salmonellosis, our study indicated that the risk could be widespread enough to be of public health importance.

In designing our survey, we hypothesized that many salmonella infections are caused by consumption of contaminated food products, particularly meats, which are known to have high levels of contamination [21, 22] and are frequently identified as the common source exposure in outbreak investigations. However, we did not find such an association between illness and consumption of meat or other food products. This could partially be because different salmonella serotypes are found in different food items, and our case-patients reflected many different serotypes. However, analyses of food items for the most common serotypes also did not yield any association of illness with specific food items (data not shown). This indicates that mechanisms that commonly cause outbreaks (e.g. undercooking of food products) could be different from those causing sporadic illness. How to interpret the protective effect of some food items (e.g. vegetables and fruits) is unclear. Although a true protective effect of certain food items is possible, memory or selection bias by controls who eat a broader range of food items is also possible. Similar effects have been reported previously in case-control studies conducted in Switzerland and Denmark [23, 24] and as part of the US Foodborne Diseases Active Surveillance Network (FoodNet) [25, and personal written communication].

Sporadic salmonella infections, when found to be associated with certain food items (e.g. raw or undercooked eggs and chicken with *S.* Enteritidis) [7–9, 26], could represent only a small proportion of widespread outbreaks, which go unrecognized because of under-reporting and geographical spread. Our study did not yield a common source exposure for the case-patients. Although that and the different PFGE patterns documented for the same serotypes indicate that sporadic case-patients in this study are likely not part of larger undetected outbreaks, this possibility cannot be excluded for very widely dispersed outbreaks including other parts of the United States. Even when an unidentified common source causes illness, infections are frequently preventable through thorough washing and cooking of food products, adherence to strict personal hygiene, and avoidance of cross-contamination.

To identify additional mechanisms for salmonella infection causing sporadic illness, researchers might have to think beyond common routes. For example, a study in Norway reported an association between indigenous sporadic salmonellosis and eating snow, and sand, or soil and having contact with wild birds [26]. In our study, the only non-food-related risk factors associated with illness were (*a*) having an elderly person using diapers in the household, which impedes personal hygiene and facilitates person-to-person transmission and cross-contamination, and (*b*) having a reptile in the household, which is a known risk factor for salmonellosis [27]. However, few case-patients reported either exposure. In general, case-patients reported potentially risky recreational activity or household exposure less frequently than controls, which could be related to their older age and increased likelihood of having an underlying medical condition. Other studies have reported a link between underlying medical conditions and salmonella infections [13, 28, 29]. Several possible explanations exist. Patients with underlying illnesses who contract salmonella might already be under medical care, causing them to seek care more readily than otherwise healthy patients. Chronically ill and older patients might be more severely affected once infected, which also could increase the likelihood of laboratory-confirmed diagnosis, which is needed for reporting disease, thus biasing reported cases towards older and chronically ill persons. However, advanced age and chronic illness may also be a true reflection of a higher disease susceptibility leading to higher incidence. A large proportion of the US population might be exposed to low-level contamination with salmonella, possibly because of cross-contamination, which might cause infection with greater frequency among persons with increased susceptibility. Targeting prevention messages to these groups at high risk is important, as is searching for broad-based policy changes that will decrease exposure among all groups.

Although other studies identified international travel as a risk factor [26, 28] our study documented no association with illness; only one case-patient reported international travel in the week before becoming ill. The Norwegian study reported that 90% of infections in Norway were acquired abroad and that no association existed between sporadic infections and domestically produced meat products [29]. Our study indicated that salmonella infections in Louisiana are acquired domestically and that prevention programmes should focus on domestic food production and distribution systems.

Our study design has several limitations. First, sporadic salmonellosis may occur as a result of many different exposures and behaviours, each of which may be responsible for only a small percentage of cases. This would tend to lower the chance of finding a statistical association between any illness and any single exposure or behaviour, especially if the study sample size is not large. Thus our failure to find an association between illness and consumption of specific foods, household exposures, and certain food-handling practices does not rule out the possibility that these risk factors could have caused a small number of cases. This effect should have the tendency to obscure true associations, not produce spurious associations, thus it should not invalidate our findings that underlying medical illnesses and lack of hand-washing are risk factors for illness. Secondly, a case-control study of this kind has the potential for recall bias, in which case-patients remember events in the past differently than do controls. Case-patients might tend to recall better what they did before becoming ill than would healthy controls. However, except for food consumption, we surveyed usual household practices, which tend to remain stable and are easily reportable. Also, for retrospective studies, questionnaires administered after disease occurrence are often the only feasible tool to obtain information regarding risk behaviours that preceded disease. Thirdly, our standardized questionnaire did not include the entire list of foods that could serve as vehicles for salmonella. Recently, new and diverse food products (e.g. fresh produce and spices) have been associated with salmonellosis [30, 31]. Fourthly, our questionnaire did not distinguish raw or undercooked from thoroughly-cooked meats, and the risk of salmonellosis associated with meat consumption varies based upon how thoroughly meats are cooked. Hence, contaminated food items could have served as the source of infection for persons in our study without being identified.

Several measures have been taken in recent years to improve food safety. Since its implementation in 1997, HACCP has decreased the level of salmonella contamination in the domestic meat supply [10]. In addition to safer food production, other population-based strategies to prevent distribution of contaminated foods to consumers should be more widely implemented. For example, food irradiation, a method of food decontamination that can be applied to the end product, including frozen products, is safe and effective in reducing pathogens without changing the taste of these products [32, 33]. Although acceptability of irradiated products by consumers is unclear, international agencies (e.g. the World Health Organization) have recommended it, the US Food and Drug Administration (FDA) has approved it for poultry, meat, and spices and several professional organizations have endorsed it. Consumers need further information regarding the safety of irradiated products, and regulatory agencies like FDA and USDA should promote such measures more. As long as the food supply continues to be contaminated, personal hygiene and safe food-preparation techniques will a cornerstone for preventing infections. Additional research to further identify mechanisms of prevention on the individual level is also warranted because of an increasing antimicrobial-resistant pattern of salmonella infections in the United States [34, 35], the ageing of the population [36], and a continuously increasing market for international food trading, which introduces new vehicles of infection [37].

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