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Foodborne general outbreaks of *Salmonella* Enteritidis phage type 4 infection, England and Wales, 1992–2002: where are the risks?

I. A. GILLESPIE[1]*, S. J. O'BRIEN[1], G. K. ADAK[1], L. R. WARD[2] AND H. R. SMITH[2]

[1] *Gastrointestinal Diseases Department, Health Protection Agency Communicable Disease Surveillance Centre, London, UK*
[2] *Laboratory of Enteric Pathogens, Health Protection Agency Specialist and Reference Microbiology Division, London, UK*

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SUMMARY

Foodborne outbreaks of *Salmonella enterica* serovar Enteritidis phage type 4 (PT4) infection ($n=497$), reported to the Health Protection Agency Communicable Disease Surveillance Centre between 1992 and 2002, were compared with other pathogens ($n=1148$) to determine factors (season, setting, food vehicles, food safety faults) associated with this pathogen. Logistic regression was applied to control for potential confounding. Foodborne general outbreaks of *S.* Enteritidis PT4 infection were more likely to occur in the spring and summer, and were more often linked to schools, private residences and residential institutions. Eggs, egg products and the use of raw shell egg were strongly associated with this pathogen. Most outbreaks were linked to cross-contamination and inadequate heat treatment. This paper describes the decline in the *S.* Enteritidis PT4 epidemic, providing evidence that control measures introduced, e.g. improved biosecurity and vaccination, have worked. Continued surveillance of human and veterinary salmonellosis is essential to detect future problems.

INTRODUCTION

Foodborne outbreaks of infectious intestinal disease (IID) usually occur as the result of a breakdown in food safety control measures or the changing epidemiology of a pathogen [1]. Whilst large outbreaks [2], or those associated with severe infection [3] or unusual aetiologies [4] attract media and scientific interest alike, the vast majority are only remembered by investigators and victims. As isolated events, such outbreaks tell us little about the epidemiology of foodborne disease. However, when pooled systematically, these outbreaks provide an effective tool for monitoring trends, identifying novel routes of infection, assessing interventions and informing policy makers.

The current national surveillance scheme for general outbreaks of Infectious Intestinal Disease was established in 1992 [5] following recommendations by the Committee on the Microbiological Safety of Food (the Richmond Committee) that 'the Communicable Disease Surveillance Centre (CDSC) with the rest of the Public Health Laboratory Service (PHLS) takes step to improve the routine central reporting of outbreaks by laboratories and local authorities, particularly of outbreaks occurring in institutions and those affecting the community at large (as opposed to family outbreaks)' [6]. An outbreak is defined as 'an incident in which two or more people, thought to have a common exposure, experience a similar illness or

* Author for correspondence: Mr I. A. Gillespie, Gastrointestinal Diseases Department, HPA Communicable Disease Surveillance Centre, 61 Colindale Avenue, London NW9 5EQ, UK.
(Email: Iain.Gillespie@hpa.org.uk)

proven infection (at least one of them being ill)' [7]. A general outbreak is defined as 'an outbreak affecting more than one private residence or residents of an institution' [7].

Initial output from this surveillance system involved scrutiny of all the data [5, 8] or of specific subsets such as setting [9, 10], mode of transmission [11, 12], vehicle of infection [13] or pathogen [14, 15]. In these, analyses were limited to frequency distributions, with little use of statistical tests. Recent output from the system has focused on particular vehicles of infection [16–18] or setting [19] and a variety of statistical tests have been employed to draw comparisons and assess the strength of associations. Whilst these methods have proved to be useful, uncontrolled confounding between variables might have existed.

This study aimed to overcome this drawback by applying logistic regression to the analysis. This technique has been used to identify independent factors for foodborne general outbreaks only once in the past but the analysis was flawed because the researchers used an exposure as the outcome of interest instead of infection/intoxication with the relevant pathogen/toxin, thus confounding their analysis [20].

The aim of this study was to identify factors which were independently associated with foodborne general outbreaks of *Salmonella enterica* serovar Enteritidis phage type 4 (PT4) infection when compared with those attributed to other pathogens.

METHODS

General outbreaks of infectious intestinal disease are reported to the CDSC by various means including Public Health and hospital laboratories, Consultants in Communicable Disease Control (CsCDC), Local Authority Environmental Health Departments, General Practitioners and reference laboratories [21]. A structured questionnaire is sent to the appropriate CCDC, with a request to complete it when the outbreak is over. Routine reminders (up to three) are sent periodically and the response rate is over 80% [8]. The questionnaire seeks a minimum set of data on each outbreak, including the setting, mode of transmission, causative organism, and details of epidemiological and laboratory investigations [22]. Data from the questionnaires, which are supplemented by microbiological typing data, are stored in a dynamic database derived from Epi-Info version 5 [23].

Outbreaks were initially included where the mode of transmission was described as mainly foodborne. It is important to note that in foodborne outbreaks, where the food was prepared takes precedence over where it was served with regard to outbreak setting. The date of onset for the index case in each outbreak was used to define the month of the outbreak and approximations of the four seasons (spring = March to May; summer = June to August; autumn = September to November; winter = December to February) were calculated. Binary variables were created to represent the outcome (outbreaks of *S.* Enteritidis infection *vs.* other pathogens) and explanatory variables [outbreak setting, season, food vehicles (including the use of raw shell egg) and contributory hygiene faults]. Individual outbreaks with missing data on the above were omitted from the analyses using those data.

A descriptive analysis was undertaken using Microsoft Excel 2000 (Microsoft Corporation, Redmond, USA). χ^2 tests for trend were calculated using Epi-Info version 6.04b. Two-sided unpaired *t* tests and risk ratios were calculated using STATA version 7 (Stata Corporation, College Station, TX, USA).

Statistical analyses were undertaken using STATA version 7. Outbreaks of *S.* Enteritidis infection were considered 'cases' whilst those attributed to other pathogens or toxins were considered 'controls'. These were compared initially using single risk variable analyses. Maximum-likelihood estimates of the Mantel–Haenszel odds ratios (OR) were calculated for each explanatory variable. Logistic regression was then applied to obtain maximum-likelihood estimates of the effect of exposures on the outcome whilst controlling for confounding effects. Variables with a *P* value of $<0{\cdot}1$ from the single risk variable analysis were included initially in the model. Step-wise exclusion was used to simplify the model: variables were removed one at a time and tested for significance using the Likelihood Ratio (LR) test with a *P* value of 0·05 as a cut-off point. A variable representing year of report was included to control for the confounding effect of temporal trends. Potential interactions (between the main effects included in the initial logistic regression model and season) were also examined using this technique.

RESULTS

Between 1 January 1992 and 31 December 2002, 7010 general outbreaks of IID were reported to CDSC,

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Table 1. *General outbreaks, foodborne general outbreaks, foodborne general outbreaks of salmonellosis and foodborne general outbreaks of* S. *Enteritidis PT4 infection, England and Wales, 1992–2002*

	General outbreaks			
Year	All	Foodborne (%)*	All foodborne salmonellas (%)†	All foodborne *S.* Enteritidis PT4 (%)‡
1992	373	224 (60)	138 (62)	89 (64)
1993	454	225 (50)	132 (59)	98 (74)
1994	490	192 (39)	92 (48)	53 (58)
1995	837	183 (22)	90 (49)	55 (61)
1996	733	165 (23)	89 (54)	50 (56)
1997	591	222 (38)	122 (55)	61 (50)
1998	610	121 (20)	58 (48)	34 (59)
1999	515	92 (18)	45 (49)	18 (40)
2000	656	96 (15)	35 (36)	17 (49)
2001	526	70 (13)	36 (51)	12 (33)
2002	1225	55 (4)	30 (55)	10 (33)
Total	7010	1645	867	497

* Of all general outbreaks.
† Of all foodborne general outbreaks.
‡ Of all foodborne general outbreaks of *Salmonella* infection.

of which 1645 (23%) were described as foodborne outbreaks (Table 1). Outbreaks of salmonellosis accounted for over half (867/1645, 53%) of these, and *S.* Enteritidis PT4 was the most commonly reported phage type (497/867, 57%). During the surveillance period, the proportion of foodborne general outbreaks of *S.* Enteritidis PT4 infection ('*S.* Enteritidis PT4 outbreaks') decreased significantly in relation to all foodborne general outbreaks of salmonellosis (χ^2 for trend 7·21, $P<0·01$) and all foodborne outbreaks of IID (χ^2 for trend 12·98, $P<0·001$).

Dynamics and impact

Over 11 000 people were affected (11 200, range 2–229, mean 23) with 505 hospital admissions (range 0–30, mean 1·4) and 28 deaths (range 0–3, mean 0·10) reported. The mean number of people affected (23 *vs.* 22, $P>0·05$), admitted to hospital (1·4 *vs.* 1·2, $P>0·05$), or reported to have died (0·10 *vs.* 0·06, $P>0·05$) in *S.* Enteritidis PT4 outbreaks was no different to the numbers in outbreaks attributed to other pathogens or toxins.

Factors associated with *S.* Enteritidis PT4 outbreaks, England and Wales, 1992–2002 – single risk variable analysis

S. Enteritidis PT4 outbreaks occurred more frequently in all the seasons compared with winter (especially summer), and were more often linked with private residences, the armed services, schools and residential institutions (Table 2). Eggs and egg products (and the use of raw shell egg in particular) were more often reported as the suspected foodborne vehicles of infection. Inadequate heat treatment and cross-contamination were reported more often in these outbreaks compared to other pathogens.

Factors independently associated with *S.* Enteritidis PT4 outbreaks, England and Wales, 1992–2002 – logistic regression analysis

Outbreaks of *S.* Enteritidis PT4 infection were more likely to occur in the summer months than foodborne outbreaks attributed to other pathogens (Table 3). Schools, residential institutions and private settings were the most likely settings. Eggs/egg dishes and the use of raw shell egg were more likely to be reported as the suspected vehicles. Cross-contamination and inadequate heat treatment were more likely to be reported as food hygiene faults.

DISCUSSION

The United Kingdom (UK) Food Standards Agency has set a target for a 20% reduction in foodborne illness by April 2006 [24, 25]. To achieve this it needs robust information on the vehicles and causes of food poisoning. Sporadic cases account for the vast majority of foodborne IID in England and Wales [6], although the food source in these cases is rarely identified. This is because confirmation involves isolating the pathogen/toxin from the food and the patient, and in many instances the food has been consumed and any residue discarded [6]. It is likely, therefore, that the epidemiological and microbiological evidence gained from outbreak investigations offers the best source of information linking food to illness, and the routine surveillance of such outbreaks provides a powerful tool available to the Food Standards Agency. With this in mind, the identification of factors distinct to specific pathogens or toxins will form an important step towards developing prevention strategies for foodborne IID.

Table 2. *Factors associated with foodborne general outbreaks of* S. *Enteritidis PT4 infection, England and Wales, 1992–2002 – single risk variable analysis*

	Percent reported				
Exposure	Cases*	Controls†	OR	*P* value	95% CI
Winter	17	18	1	—	—
Spring	50	35	2·15	0·0002	1·43–3·23
Summer	23	23	3·35	<0·001	2·34–4·79
Autumn	10	24	2·37	<0·001	1·61–3·49
Private residences	19	9	2·43	<0·001	1·79–3·29
Armed services	4	2	2·02	0·0283	1·06–3·82
Schools	5	3	1·83	0·0275	1·06–3·15
Residential institutions	12	9	1·44	0·0347	1·02–2·02
Restaurants	23	28	0·80	0·0708	0·62–1·02
Pub/bars	4	7	0·52	0·01	0·31–0·86
Other premises	1	2	0·40	0·079	0·14–1·16
Community	1	2	0·31	0·0457	0·09–1·05
Raw shell egg	37	7	7·51	<0·001	5·23–10·78
Eggs and egg products	27	5	6·49	<0·001	4·36–9·65
Salad, vegetable and fruit	5	9	0·52	0·0125	0·30–0·88
Milk and milk products	2	4	0·49	0·063	0·22–1·06
Rice	2	5	0·46	0·0441	0·21–1·00
Red meat/meat products	2	4	0·33	<0·001	0·23–0·49
Inadequate heat treatment	42	24	2·28	<0·001	1·82–2·86
Cross-contamination	37	25	1·78	<0·001	1·41–2·23
Other faults	9	12	0·71	0·0577	0·49–1·01

OR, Odds ratio; CI, confidence interval.
* Foodborne general outbreaks of *S.* Enteritidis PT4 infection ($n=497$).
† Foodborne general outbreaks of IID attributed to other pathogens ($n=1148$).

S. Enteritidis was the predominant pathogen reported as a cause of foodborne outbreaks during the surveillance period, and within this group, *S.* Enteritidis PT4 was the single most important phage type. The role of egg dishes (and in particular the use of raw shell eggs) in these outbreaks, in terms of causality and impact, is clear. Considering that outbreaks of *S.* Enteritidis infection of phage types other than PT4 ($n=167$), which share many epidemiological features with PT4, were included in the comparison group, then the effect (and therefore the impact) is probably underestimated here.

The *S.* Enteritidis epidemic in England and Wales began in the early 1980s [26], but it was not until the late 1980s that *S.* Enteritidis (and, in particular *S.* Enteritidis PT4) emerged as the most prevalent salmonella strain in humans. Subsequent epidemiological studies confirmed an association with eggs [27, 28]. The natural reservoir of *S.* Enteritidis is in rodents [29], and it has been hypothesized that the epidemic occurred as a result of the virtual elimination of *S.* Gallinarum and *S.* Pullorum from chicken flocks in the 1960s and early 1970s [30], the presence of *S.* Enteritidis in poultry and eggs and of the organism's ability to invade the reproductive tract of the chicken [31]. Early control measures [29] might have halted the rise in incidence, but it was not until a formalin-inactivated strain of *S.* Enteritidis PT4 was used to vaccinate broiler breeder flocks and commercial laying flocks [31], and improved biosecurity in layer grandparent birds [26] that the incidence of human disease dropped dramatically [32].

Outbreaks of *S.* Enteritidis PT4 infection were independently associated with schools, private residences and residential institutions. Recent research [19] suggests that outbreaks in the home occur when individuals cater for larger numbers than they are used to, and this is likely to be compounded by a lack of food hygiene training in the domestic environment. Individuals undertaking catering in this environment need to be made aware that eggs might be intermittently contaminated with *Salmonella* [33], that contamination of hands, utensils and work surfaces is possible during the preparation of simple egg dishes

Table 3. *Factors independently associated with foodborne general outbreaks of* S. *Enteritidis PT4 infection, England and Wales, 1992–2002 – logistic regression analysis*

Exposure	OR	*P* value	95% CI
Summer (*vs.* other seasons)	1·8	<0·001	1·3–2·5
Schools	2·6	0·037	1·1–6·4
Residential institutions	2·0	0·012	1·2–3·6
Private residences	1·8	0·006	1·2–2·8
Eggs and egg products	6·6	<0·001	4·2–10·4
Raw shell egg	3·1	<0·001	1·9–5·1
Desserts	2·9	<0·001	1·8–4·9
Red meat/meat products	0·4	<0·001	0·3–0·7
Cross-contamination	2·9	<0·001	2·1–4·1
Inadequate heat treatment	2·1	<0·001	1·5–2·9

OR, Odds ratio; CI, confidence interval.

[34], and that dishes which contain raw/undercooked eggs (e.g. mayonnaise, mousses, etc.) pose a particular risk. Caterers in schools and residential institutions are governed by the same food safety legislation [35] as elsewhere, and, therefore, the standard of hygiene in these premises is likely to be no better or no worse. Their inclusion probably reflects a selection bias, as a higher number exposed in these premises increases the chances of the outbreak being identified. Where possible, pasteurized liquid egg should be used in the preparation of dishes containing raw egg, in line with the advice of the Chief Medical Officer (CMO) [36].

The fact that *S.* Enteritidis PT4 outbreaks were independently associated with summer is not surprising. Estimates of the infective dose required for human illness vary from <1000 to many million organisms [37], and volunteer studies have shown that attack rates increase with increasing inoculum size [38]. Salmonellas grow readily in inadequate storage conditions [39], and it is possible that elevated ambient temperatures in the summer months allow microbial proliferation, increasing the inoculum on contaminated food, and hence the attack rate. The effective storage of food (and especially eggs) throughout the year, in line with current legislation [40], is essential if *S.* Enteritidis PT4 outbreaks are to be prevented.

Inadequate heat treatment (especially in the winter months) and cross-contamination were the food hygiene faults independently associated with *S.* Enteritidis PT4 outbreaks. If these outbreaks are to be avoided then the basic rules of food hygiene described above should be applied. Raw and cooked foods should be separated to reduce the possibility of cross-contamination, and all foods should be stored at temperatures which inhibit microbial growth. Pasteurized liquid egg should be used wherever possible in dishes that require uncooked egg. If this is not possible then fresh eggs from assured schemes (e.g. the 'Lion Code' and 'Laid in Britain' schemes in the United Kingdom which employ vaccination and competitive exclusion respectively to reduce/eliminate contamination) should be used and vulnerable groups should be discouraged from eating such preparations.

When interpreting the results from this type of study it is important to appreciate the limitations of the surveillance system from which the data arose and the analytical method employed.

There is a danger of introducing information bias in the investigation and reporting of outbreaks if the 'usual suspects' are sought. For example, when presented with an outbreak of *S.* Enteritidis PT4 infection in the middle of July at a wedding reception, investigators might be inclined to follow their instincts and enquire about consumption of egg dishes or the use of raw shell egg. Such practices should be discouraged as they will overestimate the role of certain foods in disease. However, whilst investigators might be influenced by previous knowledge with regard to food vehicles, this does not alter where or when an outbreak takes place.

More than one food vehicle (generally up to three) can be reported for any given outbreak and this might introduce bias in the analysis as the inclusion of one food variable might confound the effect of another, especially if both are commonly reported in the same outbreak (and are therefore highly correlated). The results suggest that this has not occurred, as several food types were independently associated with the outcome of interest.

In a case-control study, exposures in ill cases that differ greatly from well controls can, assuming an appropriate study has been carried out and analysed properly, be considered risk factors (or protective effects) for the outcome of interest. This is not the case in this study, as 'cases' (outbreaks attributed to one pathogen) were compared with 'cases' (outbreaks attributed to all other pathogens), and, therefore, exposures of a similar level in both comparison groups will not be identified or will be underestimated. This study is still worthwhile, however, as the analysis will identify the most important effects, which realistically are the ones which policy makers need to address. For example, examination of the percentages in Table 2 might suggest that restaurants have an important role in *S*. Enteritidis PT4 outbreaks. However, it is only when logistic regression is applied that it becomes apparent that the foods prepared and served in these premises appear to be more important than the premises themselves, indicating that control further up the supply chain might be necessary. This does not, however, absolve restaurants from their duties of preventing infection with *S*. Enteritidis PT4 or other foodborne pathogens through maintaining good standards of food hygiene.

Finally, although logistic regression has been used to control for the effect of confounding between known variables, it is possible that confounding from unknown sources is taking place. However, the information collected on the outbreaks is sufficiently extensive to reduce the likelihood of this taking place.

CONCLUSION

The reduction of human salmonellosis, and *S*. Enteritidis PT4 infection in particular, is a public health imperative. In order to achieve this, policy makers must target their intervention strategies effectively and our results suggest that the reduction of contamination in eggs is vital to achieving this. The decline in outbreaks of *S*. Enteritidis PT4 infection, described in this paper and mirrored in laboratory reports, is probably due to the vaccination of chicken flocks and is to be welcomed. However, it is possible that an ecological niche now exists, and it is therefore essential that surveillance of human and veterinary salmonellosis is of sufficient quality to detect future problems before they escalate to the size of the *S*. Enteritidis PT4 epidemic. The application of logistic regression, although not without its limitations, provided a quick and effective method of identifying the factors distinct to specific pathogens, paving the way for the development of prevention strategies. Furthermore, continued analysis of the dataset with time will facilitate the assessment of interventions, the investigation of emerging pathogens and the identification of novel food vehicles or routes of transmission.

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