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A prolonged outbreak of *Salmonella* Infantis associated with pork products in central Germany, April–October 2013

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SUMMARY

One of the largest and longest *Salmonella* outbreaks in Germany within the last 10 years occurred in central Germany in 2013. To identify vehicles of infection, we analysed surveillance data, conducted a case-control study and food traceback. We identified 267 cases infected with *Salmonella* Infantis with symptom onset between 16 April and 26 October 2013 in four neighbouring federal states. Results of our study indicated that cases were more likely to have eaten raw minced pork from local butcher's shops [odds ratio (OR) 2·5, 95% confidence interval (CI) 1·1–5·8] and have taken gastric acid-reducing or -neutralizing medication (OR 3·8, 95% CI 1·3–13) than controls. The outbreak was traced back to contaminated raw pork products found in different butcher's shops supplied by one slaughterhouse, to pigs at one farm and to an animal feed producer. Characterization of isolates of human, food, animal, feed, and environmental origin by phage-typing and pulsed-field gel electrophoresis confirmed the chain of infection. Insufficient hygiene standards in the slaughterhouse were the most probable cause of the ongoing transmission. We recommend that persons taking gastric acid suppressants should refrain from consuming raw pork products. Improving and maintaining adequate hygiene standards and process controls during slaughter is important to prevent future outbreaks.

Key words: Epidemiology, foodborne infections, outbreaks, public health, *Salmonella*.

INTRODUCTION

Salmonella enterica subspecies *enterica* serovar Infantis (*S.* Infantis) is a frequent source of foodborne infections in most industrialized countries, primarily causing gastroenteritis [1–3]. Large outbreaks associated with food products (e.g. raw or undercooked chicken, eggs, pork, and beef) have been reported [2–6]. Strains associated with such outbreaks have been found to circulate for periods of more than 10 years indicating a high stability of these clones [4, 7]. *S.* Infantis can tolerate adverse physical conditions (e.g. dehydration) relatively well, and this may enhance its ability to survive in the food chain [8].

S. Infantis has been identified in contaminated feeds for livestock and domestic pets (e.g. oilseed, dog chew, dry dog food, and beef trimmings) and produces asymptomatic

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infection in chickens, pigs, and cattle, all relevant reservoirs for human infections [9, 10]. Asymptomatic food-handlers have been similarly associated with infections and outbreaks in humans via contaminated food [11]. Besides indirect transmission by food, *S.* Infantis can also be transmitted directly from infected animals to humans or by human-to-human [9, 12].

Both in the European Union and in Germany, *S.* Infantis is the third most common *Salmonella* serovar infecting humans, after *S.* Enteritidis and *S.* Typhimurium (including monophasic *S.* Typhimurium 1,4,[5],12:i:-), with an increasing yearly number of reported isolates [1]. In Germany, the proportion of *S.* Infantis in all human *Salmonella* isolates increased from 0·6% to 3·6% between 2006 and 2013 [13]. From 2001 to 2013 the highest yearly incidence rates of salmonellosis caused by *S.* Infantis were reported by the two central federal states Thuringia (mean 2·1/100 000) and Saxony-Anhalt (mean 1·5/100 000) [13]. Several outbreaks in families and communities caused by this serovar have been described in these states in the past [4, 7, 14–16].

Between November 2012 and June 2013, cattle from farm A in Thuringia tested positive for *S.* Infantis phage type (PT) 29. Investigations identified rapeseed expeller (a by-product of oil production used as animal feed) as the source of infection, and the origin of the expeller was traced back to animal feed producer X in Thuringia. The producer was officially prohibited from further selling rapeseed expeller on 26 February 2013. Forward tracing indicated that three additional cattle producers in Thuringia and two wholesalers in Hesse and Saxony had received that product. This led authorities to implement an immediate market withdrawal of the product. In addition, cattle from farm A were only slaughtered after a negative test result for *Salmonella* in a slaughterhouse in the east of Thuringia.

In May 2013, the National Reference Centre for *Salmonella* and other Bacterial Enteric Pathogens (NRC) in Wernigerode, Germany, noted an increase of *S.* Infantis PT29 isolates from patients in Thuringia. The state public health and food safety authorities together with the local public health and food safety authorities undertook an epidemiological investigation to identify the source and vehicles of the outbreak.

METHODS

Outbreak identification

The detection of *Salmonella* spp. in combination with acute symptoms is mandatorily notifiable to the local health authorities in Germany [17]. A review of the Thuringian surveillance data on notifiable infectious diseases indicated that *S.* Infantis cases had increased from an average of <1 case per week between January 2001 and April 2013 (median 0, mean 0·69, range 0–9) to ten cases in week 18 of 2013.

Case definition

Based on the German national case definition [18] a case was defined as acute gastroenteritis with a culture-confirmed *S.* Infantis infection in residents of Thuringia, the southern region of Lower Saxony, the southern part of Saxony-Anhalt and the northeastern districts of Hesse with symptom onset between 16 April and 26 October 2013 (see map in Fig. 1). Cases infected with a different phage type than the outbreak strain *S.* Infantis PT29 were excluded.

Descriptive epidemiology and hypothesis generation

We conducted passive case-finding by analysing the notification data of the outbreak area by time (plotting cases by date of symptom onset), person (median age, age range, proportion of cases by sex, proportion of hospitalized cases), and place (incidence rates by region). Initial case interviews were carried out by different local health authorities in May 2013. The results were analysed regarding frequency of exposures and an explorative questionnaire aimed at generating hypotheses concerning the source of infection was developed. We collected information on clinical characteristics (e.g. symptoms, onset of disease, location of infection), about possible exposures 3 days before symptom onset including consumption of 97 food products, the corresponding shopping venues, preparation of meals, eating in restaurants, and contact with animals. The exploratory questionnaires were analysed regarding frequency of food consumption. As a result we hypothesized that raw pork products were associated with infection.

Case-control study

In order to test the hypothesis, we conducted a case-control study between June and September 2013. Cases were included if they met the case definition and were notified to the authorities in Thuringia or Lower Saxony during the 4 months of the study. Controls, defined as persons living in the outbreak region without suffering from acute gastroenteritis

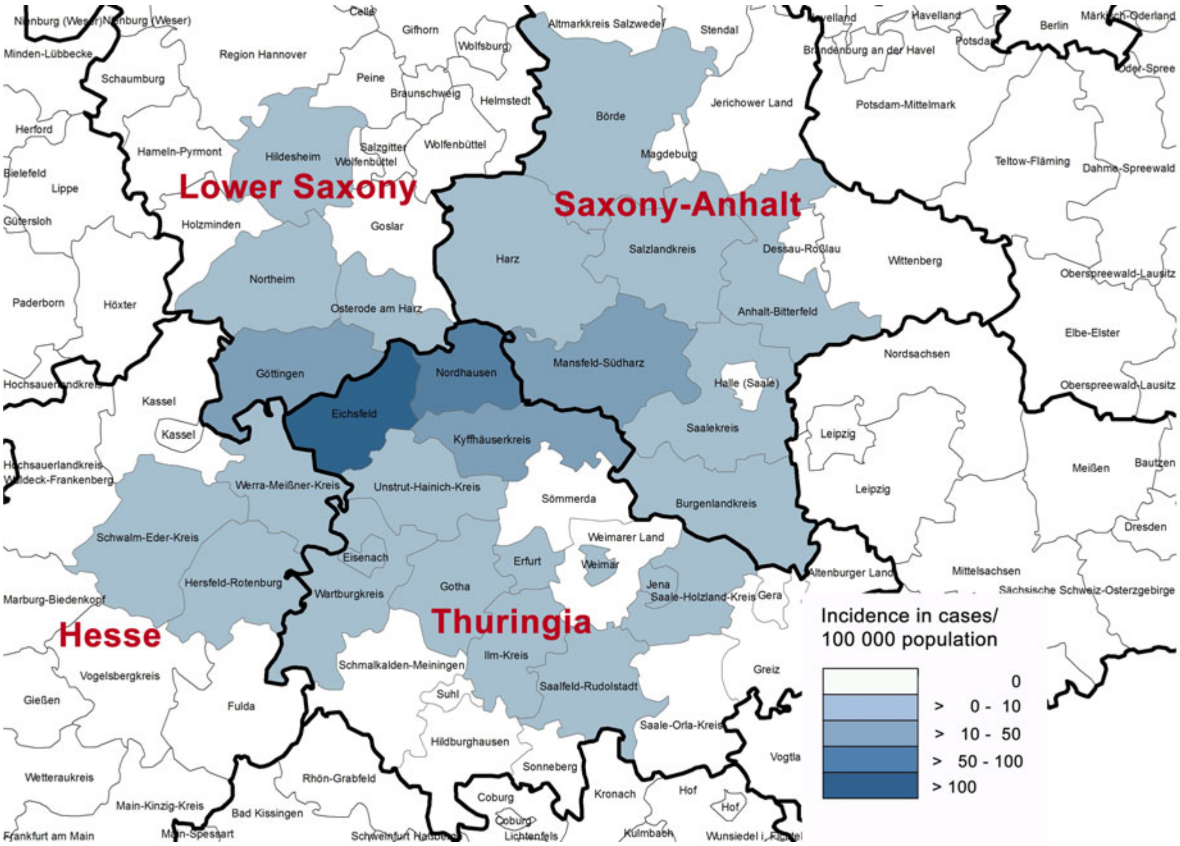

Fig. 1. Reported incidence rates of *Salmonella* Infantis cases per 100 000 inhabitants by region of residence, 16 April–23 October 2013, central Germany ($n = 267$).

within 10 days before interview, were frequency-matched on a 1:1 basis by region, and selected by random digit dialling. Cases and controls were excluded if they were aged <18 years and reported travelling outside the outbreak region within 10 days before symptom onset or interview, respectively. Staff from the state health authorities interviewed participants by telephone using a standardized questionnaire developed in collaboration with local and state partners that collected information on demographic characteristics, symptoms, onset of disease, chronic underlying medical conditions, food preferences, and frequency of consumption. Furthermore, participants were asked about preparation and consumption of raw and cooked pork products and other food items that ⩾50% of the cases exploratively interviewed had eaten, about shopping venues where they had purchased their food, use of gastric acid-reducing or -neutralizing medication, and contact with cats or dogs. These questions referred to the 3 days before disease onset for cases or 8–10 days before interview for controls.

We performed univariate and multivariable logistic regression analysis using Stata v. 12 software (StataCorp, USA) and calculated exposure-specific odds ratios (OR) and 95% confidence intervals (CI). All risk factors with OR >1 and a P value <0·1 by univariate analysis were included in the multivariable analysis. Logistic regression models were built using forward selection of variables with $P < 0{\cdot}05$, adjusted for age group and sex. Wilcoxon's rank sum tests were used for comparison of continuous variables in two groups, and χ^2 tests for categorical variables.

Traceback and environmental investigations

Between 25 July and 20 October 2013, the local food safety authorities collected food and environmental samples from butcher's shops where cases had been buying pork products. They traced products back to the suppliers along the food supply chain, took environmental and animal faecal specimens for microbiological analyses, and checked the results of the samples taken routinely by the producers during the production process. In addition they checked the results of the serological monitoring of pigs between April and November 2013 that were tested as part

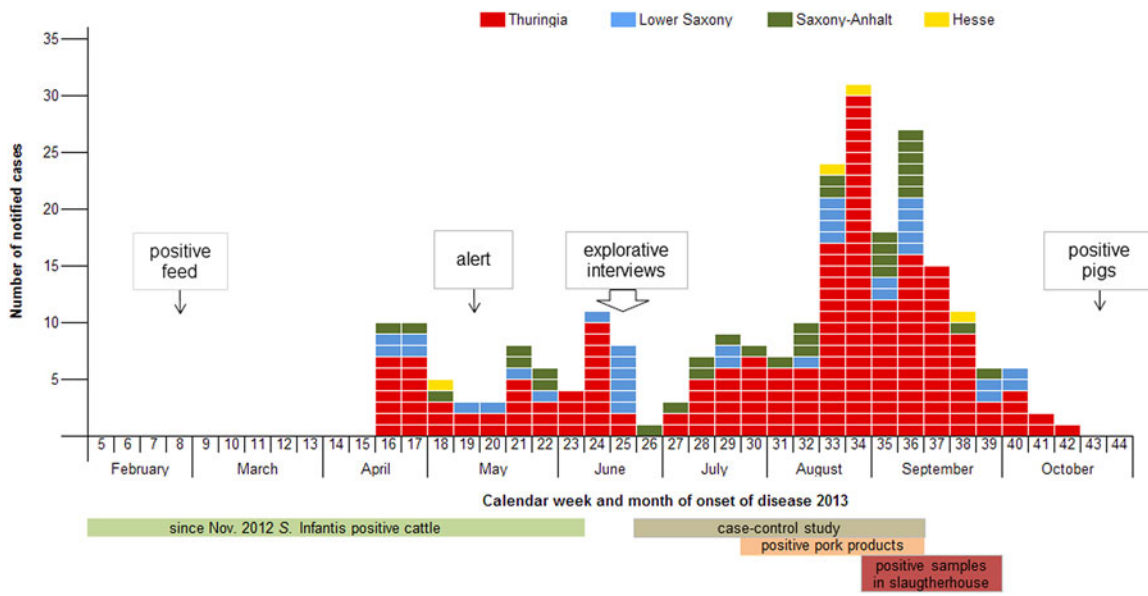

Fig. 2. Notified *Salmonella* Infantis cases by onset of disease ($n = 253$) within the federal states of Thuringia, Lower Saxony, Saxony-Anhalt, and Hesse, April–October 2013, as well as the investigation timeline, measures taken and results.

of the mandatory German *Salmonella* control programme [19]. The local health authorities collected stool specimens for *Salmonella* testing from employees at butcher's shops and at the other inspected facilities.

Microbiological investigation

S. Infantis isolates from stool specimens of patients, food samples, environmental samples, and animal faecal specimens were phage-typed following the standardized NRC protocol [4]. In addition, pulsed-field gel electrophoresis (PFGE) of isolates from stool specimens collected from cases living in Thuringia and Lower Saxony, animal faecal samples, food samples, and environmental samples was performed using *Xba*I restriction enzyme following the PulseNet CDC protocol [20].

RESULTS

Descriptive epidemiology

In total, 267 cases including one death were notified to the local public health authorities in 27 districts of Thuringia, Lower Saxony, Saxony-Anhalt, and Hesse (median age 56 years, range 0–93 years, 55% males, 32% hospitalized). The dates of disease onset were known for 253 outbreak-related cases (Fig. 2). The first case occurred on 16 April 2013. Several smaller peaks occurred in April, May, and June, but most cases were reported in August and September comprising 72 and 77 cases, respectively. The last case was reported on 20 October 2013.

The districts of Eichsfeld and Nordhausen in northern Thuringia reported the highest incidence rate with 103 and 56 cases/100 000 population, respectively. The incidence rates in three bordering districts in Thuringia (district Kyffhaeuserkreis), Lower Saxony (Goettingen) and Saxony-Anhalt (Mansfeld-Suedharz) ranged between 11 and 15 cases/100 000 population. Further cases were notified to the health authorities in 22 neighbouring districts (ten in Thuringia, six in Saxony-Anhalt, three in Hesse, three in Lower Saxony), with incidence rates ranging from 0·4 to 6·7 cases/100 000 population (Fig. 1).

Analyses of the initial interviews with 16 cases carried out by the local health authorities in May 2013 indicated that 13 (81%) cases had consumed cooked pork products, eight (50%) raw pork products, five (31%) eggs, three (19%) fish, one (6%) beef, and one (6%) poultry. Seven (44%) of these 16 cases had completed exploratory questionnaires. Food items eaten most often included cheese and tomatoes (6/7, 86% each), fried pork sausages, gummy bears (gelatine-based fruit gum candies), raw minced pork, cooked pork, and yoghurt (4/6, 67% each). Beef products were only eaten by two (33%) out of six cases. The types and brands of cheese, tomatoes, gummy bears, and yoghurt were different. Because raw pork is a known risk factor for salmonellosis in the outbreak area, we hypothesized that raw pork products were the source of the outbreak.

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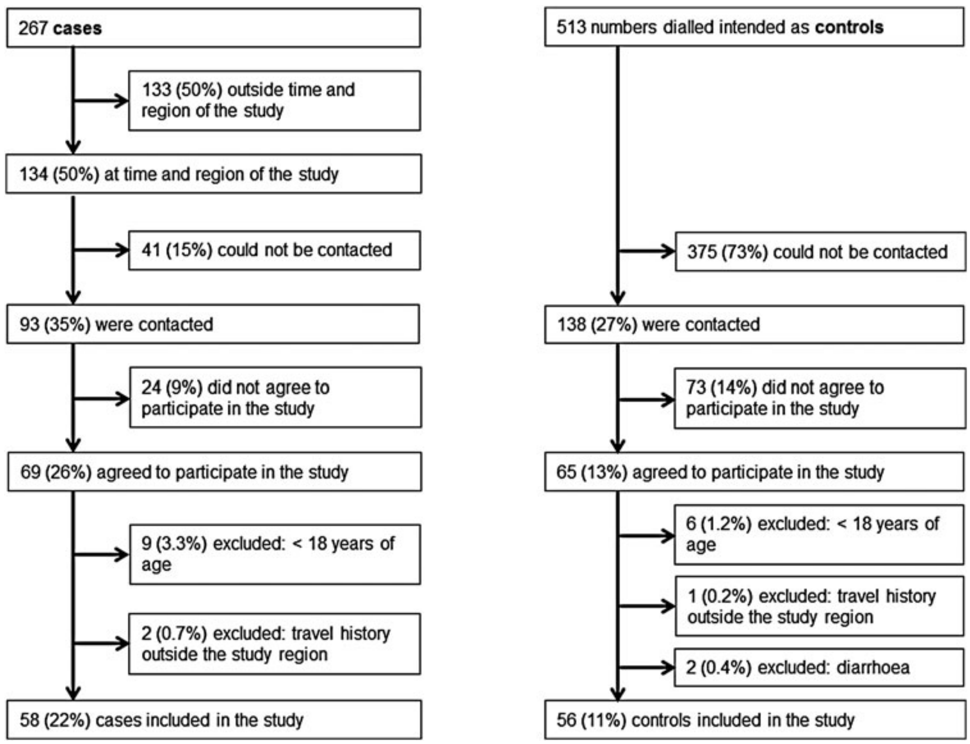

Fig. 3. Flow chart of cases and controls enrolled in the case-control study of Thuringia and Lower Saxony between June and September 2013.

Case-control study

Of 267 cases, 134 were reported during the period of the case-control study in Thuringia and Lower Saxony. Of the 134 cases 41 could not be contacted by telephone, 24 of the 93 contacted cases refused to participate. Eleven cases did not meet the inclusion criteria for study participation. Thus, in total 58 (22%) cases were included in the study (Fig. 3). We dialled 513 numbers with random digit dialling, seeking to recruit controls from which 138 persons could be contacted, and 65 agreed to participate. Of those, nine did not meet the inclusion criteria, resulting in a final count of 56 controls (11% of the dialled numbers) participating in the study.

Compared to controls, cases did not differ in terms of age (median age of cases *vs*. controls: 54 years *vs.* 56 years, respectively, $P = 0{\cdot}7$), residence (in Thuringia: 89% of cases *vs.* 91% of controls, $P = 0{\cdot}7$) and sex (male: 55% of cases *vs.* 41% of controls, $P = 0{\cdot}13$).

Cases were more likely to have taken gastric acid-suppressant medication before onset of acute gastroenteritis (32% *vs.* 11%, OR 3·8, 95% CI 1·3–13) than controls before the interview. Sixty-seven percent of 54 cases and 45% of 56 controls had eaten raw minced pork (OR 2·5, 95% CI 1·1–5·8). All other exposures, food items, demographics and habits were not associated with illness. Results of food preference analysis indicated that four (7·3%) of 55 cases and ten (18%) of 56 controls never consumed raw minced pork. By contrast, 12 (22%) of 55 cases and five (8·9%) of 56 controls consumed it several times a week or even daily (OR 6·0, 95% CI 1·0–34). In a multivariable analysis model that adjusted for age and sex, only consumption of raw minced pork and acid-suppressant medication remained associated with *S.* Infantis infection (Table 1).

Traceback and environmental investigation

On 15 July 2013, we informed the state and local food safety authorities about the results of the explorative interviews and the interim results of the case-control study. Nineteen butcher's shops that were mentioned more than once by cases were investigated by the local food authorities. These authorities checked the results of the samples taken routinely by the producers during the process of minced pork and sausage production (Fig. 4). In addition, 132 food samples and 150 environmental samples for microbiological testing were taken. The local public health authorities

Table 1. *Main results of the case-control study. Reported exposures in the 3 days before onset of symptoms in cases, or 8–10 days before interview in controls. Food preference analysis among* Salmonella *Infantis-infected cases and controls. Selected results of univariate and multivariable logistic regression analysis with P < 0·05 or odds ratio ⩾ 1·0, central Germany 2013*

	Cases			Controls				
Exposure	*n*	*N*	%	*n*	*N*	%	OR	(95% CI)
Univariate analysis								
Gastric acid suppressants	18	57	32	6	56	11	3·8	(1·3–12·8)
Raw minced pork	36	54	67	25	56	45	2·5	(1·1–5·8)
All raw pork	50	55	91	46	55	84	2·0	(0·5–8·0)
Purchase in butcher's shop*	44	58	76	37	56	66	1·6	(0·7–4·0)
Gummy bears†	17	55	31	12	54	22	1·6	(0·6–4·1)
Cooked pork	27	49	55	28	56	50	1·2	(0·5–2·8)
Contact with cats or dogs	28	56	50	25	53	47	1·1	(0·5–2·5)
Raw fresh pork sausage	17	51	33	19	56	34	1·0	(0·4–2·3)
Food preference analysis: raw minced pork								
Never	4	55	7·3	10	56	18	–	Reference
⩽1 per month	16	55	29	19	56	34	2·1	(0·5–8·3)
1 every 2 weeks	13	55	24	9	56	16	3·6	(0·8–16·6)
1 per week	10	55	18	13	56	23	1·9	(0·4–8·3)
Several times a week	12	55	22	5	56	8·9	6·0	(1·0–34·4)
Multivariable logistic regression including age group, sex, raw minced pork and gastric acid suppressants								
Gastric acid suppressants							3·4	(1·1–10·1)
Raw minced pork							2·2	(1·0–5·0)

OR, Odds ratio; CI, confidence interval.
* Purchase of raw pork, minced pork in a butcher's shop as a loose product, not pre-packaged in a supermarket.
† Gelatine-based fruit gum candies.

collected 263 stool samples from employees. All the investigated butcher's shops were supplied with pork from the same slaughterhouse. Inspection of the slaughterhouse by the food safety authorities revealed major problems in terms of food-processing hygiene. This included insufficient cleaning and disinfection of personnel's hands, of cutting boards, knives, saws, and transport boxes. Between 25 July and 20 October 2013, 86 stool samples of employees and 121 environmental samples, most of them taken after the daily cleaning and disinfection were collected at this slaughterhouse.

Pigs supplied to that slaughterhouse were traced back to farms. Investigations of these pig farms with environmental and faecal sampling did not lead to the detection of *S.* Infantis. Traceback of a *S.* Infantis-positive sample from a carcass of a sow directed investigations to a farm of breeding and fattening pigs (farm B, Fig. 4). On 2 and 20 September 2013, a total of 76 environmental and faecal samples were collected from that farm.

Investigation of feed supply relationships indicated that in February 2013, animal-feed producer X delivered rapeseed expeller contaminated with *S.* Infantis PT29 via a wholesaler from Saxony to pig farm B.

Results from the environmental investigation

S. Infantis was grown in four raw pork products collected from three butcher's shops between 24 July and 2 September 2013 [in one raw fresh pork sausage intended for frying (bratwurst), one fresh smoked sausage with garlic, and two raw minced pork samples (Table 2)]. Eight stool samples from employees of five different butcher's shops tested positive for *S.* Infantis. All environmental swabs from the butcher's shops tested negative. Between 22 August and 27 September 2013, four environmental swabs from the slaughterhouse were positive for *S.* Infantis. These had been collected on four different days and included the following sources: a hand-basin in the delivery area, a chain glove of a slaughterer, a hand-washing facility in the production area, and a carcass from a sow.

Furthermore, on 7 August and 10 September 2013, the viable colony counts of total bacteria and of

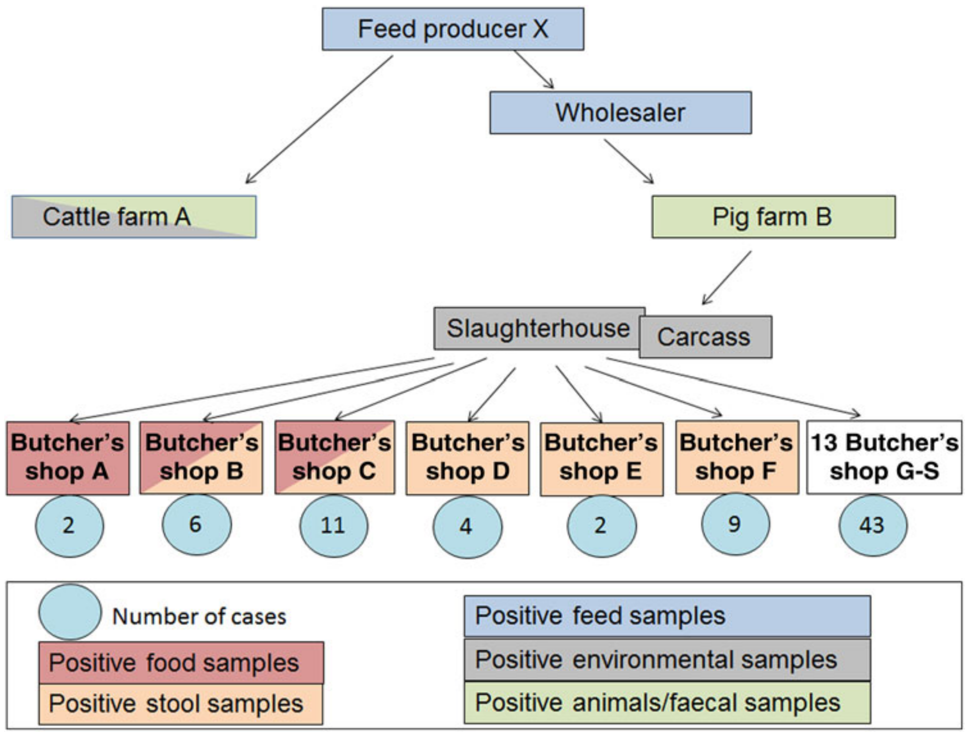

Fig. 4. Flow diagram of the food supply chain. The diagram indicates the number of cases that were connected to different butcher's shops, supplied by one slaughterhouse with pork products. One *Salmonella* Infantis-positive carcass led to pig farm B and further to feed producer X. The same contaminated feed was supplied to pig farm B and cattle farm A with *S*. Infantis-infected animals. The colour-coded key indicates the different types of samples that were positive.

Table 2. *Test results for* Salmonella *Infantis from six butcher's shops, one slaughterhouse and one pig farm between 24 July and 20 October 2013 in Thuringia, Germany*

	Food samples		Stool specimen		Environmental swabs		Animal samples	
Origin	Positive	*N*	Positive	*N*	Positive	*N*	Positive	*N*
Butcher's shop								
A	1	8	0	5	0	10	n.a.	n.a.
B	1	8	1	17	n.d.	n.d.	n.a.	n.a.
C	2*	6	2	10	0	30	n.a.	n.a.
D	0	15	2	20	n.d.	n.d.	n.a.	n.a.
E	0	3	2	10	0	19	n.a.	n.a.
F	0	8	1	35	0	10	n.a.	n.a.
Slaughterhouse	n.a.	n.a.	0	86	4	121	n.a.	n.a.
Farm B	n.a.	n.a.	n.d.	n.d.	0	76	4	6
Total	4	48	8	183	4	266	4	6

n.a., Not applicable; n.d., not done.
* Positive samples detected by the producers during the production process.

coliform bacteria were high on objects (tables, sinks, boxes, saws, doors, walls) in several production areas (cold store, slaughter area, cutting area) after the daily cleaning and disinfection. Stool samples of 86 employees of the slaughterhouse tested negative.

The 76 environmental and faecal samples collected from farm B did not grow *Salmonella*. The results of the serological testing of pigs did not indicate a current *Salmonella* infection in the pig herd (3/62, 5% antibody-positive pigs). However, in October 2013,

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S. Infantis was isolated from fetuses aborted by two sows from farm B (Table 2). The isolates from these fetuses were not available for further analysis.

Microbiological investigation

Results from cases

A total of 182 isolates from stool specimens initially attributed to the outbreak were available for phage-typing. Of these, 175 isolates including 47 isolates from the 58 cases participating in the case-control study belonged to PT29.

One specimen from a case living in the outbreak region within Saxony-Anhalt and three specimens from cases living in the outbreak region within Lower Saxony were not typable (reacted but did not conform to definite or provisional types). Two samples from Saxony-Anhalt and one sample from Lower Saxony belonged to PT1.

Seventeen *S*. Infantis PT29 isolates from cases (including six isolates originating from patients included in the case-control study) were examined by PFGE, and all shared the identical PFGE pattern XB27 (NRC internal nomenclature).

Results from the environmental investigation

Three of the four *S*. Infantis isolates from pork products were available for phage-typing, as well as two strains isolated from faeces of cattle, and the four isolates from environmental samples of the slaughterhouse (including the carcass of the sow). All *S*. Infantis isolates were identified as PT29.

Three isolates from faecal samples of cattle, one isolate from minced pork, one isolate from the fresh raw sausages for barbecue, as well as two isolates from environmental swabs taken at the slaughterhouse (carcass of the sow and the hand-washing facility) were typed by PFGE. All showed the same PFGE pattern, XB27, which was indistinguishable from the pattern of the isolates from cases.

Control measures

In August 2013, the local food safety authority published a consumer advice notice on careful transportation, handling and consumption of raw minced meat. Refrigerated transportation and immediate consumption on the same day of purchase was recommended, as well as careful attention to food preparation hygiene.

To prevent further cross-contamination and introduction of *Salmonella* in the slaughterhouse, we recommended the following measures:

- Improvement of cleaning and disinfection, as well as process control at lairage (where pigs rest before they are slaughtered), during slaughter, cutting and transportation of pork.
- Routine collection of environmental samples in the slaughterhouse at different sites of the production area after cleaning and disinfection as well as collection of swabs from carcasses according to EU regulations.
- Structural modifications of the hygiene system, especially in the sluice where the slaughterhouse workers have to clean and disinfect their footwear and hands.
- The installation of regular training in hygiene practices for employees handling pigs, carcasses and pork during slaughter and further processing.
- Careful and regular analysis of results of serological monitoring of slaughter pigs that were tested as part of the mandatory German *Salmonella* control programme [19] by the slaughterhouse.
- Additional risk-oriented serological and faecal sampling, especially for pigs intended for raw pork products.

DISCUSSION

Descriptive epidemiology, hypothesis generation and case-control study

We describe one of the largest *Salmonella* outbreaks within the last 10 years in Germany. It involved 267 cases in four central German federal states and affected mostly middle-aged and elderly people.

We found that consumption of raw minced pork was associated with *S*. Infantis infection. As described in other studies, there also was an association between use of gastric acid-suppressant medications and illness [21, 22]. Spiced raw minced pork is a typical local dish in the region of the outbreak. Consumption is very common with only 18% of the controls stating that they never eat raw minced pork.

Limitations of the case-control study

Our investigation has some limitations. The high number of controls exposed to raw minced pork and other raw pork products in our case-control study may have resulted in an underestimation of the association between salmonellosis and consumption of raw minced pork as well as other raw pork products. The recall bias of these exposures may have been greater in cases, as the time interval between food consumption in question and interview was longer in cases compared to controls. Furthermore, only 58 of 267 outbreak cases and 56 controls could be interviewed for the case-control study, and this resulted in relatively wide CIs in the statistical analysis. However, for the association between salmonellosis and raw minced pork the CI was still >1, making this a significant association. Due to the low participation, a potential additional vehicle may have been missed. Additional possible risk factors that were not investigated may have influenced the outcome. Examples are the immune status of the consumers and the numbers of salmonellae in pork. The latter can be influenced by the time between purchase of raw pork and consumption and the temperature during transportation and storage. However, the presence of *S*. Infantis PT29*Xb*27 in pork, in the slaughterhouse, in pigs, and in animal feeds confirmed the result of the epidemiological investigations that suggested that raw pork products were the main vehicle of infection.

Traceback of pork products, environmental investigation and microbiology

On the basis of our study results, pork products were traced back to 19 butcher's shops, where *S*. Infantis was detected in stool samples of employees, in raw minced pork and in other raw pork products. These products were not withdrawn at the time of microbiological sampling, and due to their short shelf-life they had been consumed by the time microbiological results were received. Employees of the butcher's shops who tested positive for *Salmonella* were prohibited from participating in food service activities according to section 42 of the German Infection Protection Act [17].

The contaminated raw pork products were traced back to one slaughterhouse where subsequent environmental samples also tested positive for *S*. Infantis: among these was a swab sample from carcass of a sow. The source of the sow was traced back to farm B, where *S*. Infantis was detected in aborted fetuses.

Salmonella can be introduced into pig farms by transmission from newly introduced infected animals, contaminated rodents, surface water or animal feeds. However, effective removal of *Salmonella* from pig farms is challenging, as cleaning and disinfection of slatted floors, control of rodents, and optimization of management and hygiene measures are difficult.

In this outbreak, contaminated rapeseed expeller supplied to farm B was a plausible source of infection of the pigs. Analysis of the animal-feed supply chain indicated that the same contaminated feed was supplied to cattle farm A resulting in *S*. Infantis-infected cattle, as well as to pig farm B identified in this outbreak. Livestock feed is susceptible to contamination during cultivation, processing, and storage. Cereals and oilseeds may become contaminated in the field through fertilization of the cultivated area by animal manure. During processing and storage, feeds may become contaminated by unhygienic production environments or by wildlife excreta. Prevention of recontamination and control of moisture throughout the production chain are thus critical factors for controlling *Salmonella* in feed production and supply [23, 24].

Phage-typing and PFGE analysis of isolates from human, pork, environmental, cattle, and feed samples pointed to an identical microbiological clone of *S*. Infantis (PT29*Xb*27). Taking into account the findings of our traceback investigations, the most probable route of transmission was that the feed contaminated by the outbreak strain had infected the pigs. It is plausible that poor hygiene practices in the slaughterhouse led to cross-contamination of other carcasses from infected pigs. As a consequence, pork products from these pigs being eaten raw caused human infections.

Explanations for the prolonged outbreak

The 2013 outbreak lasted over 6 months, indicating that pork products were contaminated for a long time. The shelf life of raw minced pork and other fresh products is short. Hence, there are two possible explanations for the prolonged outbreak. First, there may have been a frequent new introduction of *S*. Infantis-infected pigs to the slaughterhouse. However, only one *S*. Infantis-infected pig farm was found and, in that farm, *S*. Infantis was detected only in the aborted fetuses of two sows. The second possibility was an ongoing circulation of *S*. Infantis in the slaughterhouse because of inadequate hygiene standards. Detection of *S*. Infantis and other bacteria on several occasions and at different production steps after cleaning and disinfection was consistent with this hypothesis. In 2012, the same slaughterhouse had been associated with a large outbreak of salmonellosis caused by minced pork that was contaminated with *S*. Panama [16].

There are other reports of prolonged outbreaks associated with slaughterhouses. From April to August 1993, an outbreak associated with *S*.

Infantis-contaminated pork products from a single slaughterhouse in Denmark lasted 4 months [3]. Another outbreak in Denmark in 2010 lasted for almost 7 months and was associated with prolonged circulation of a *S.* Typhimurium strain in a slaughterhouse [25]. Even after closing the slaughterhouse twice for disinfection, the outbreak continued for a further 3 months. All these findings support the conclusion that poor hygiene in the slaughterhouse is the underlying cause of this *S.* Infantis outbreak.

S. Infantis can effectively form biofilms on stainless-steel surfaces that are used in food-processing facilities [26]. Therefore, this equipment is very difficult to clean, and this can lead to recurrent contamination [25, 26]. One study described a higher prevalence of *Salmonella* on pig carcasses and in the environment at the point of slaughter compared to pigs and the environment on farms [27]. Cross-contamination between primarily infected and non-infected pigs or carcasses was found at the lairage, during the evisceration process and during further processing of carcasses.

After (i) the information from our explorative interviews, (ii) the interim results of our case-control study indicated contaminated pork as a source, and (iii) positive cultures were obtained from pork samples, these findings were communicated to the food safety authorities. Nevertheless, the outbreak continued for further 3 months. Administrative hurdles, communication problems between health and food safety authorities and some delays in traceback investigations did not allow for adequate and timely control measures, and this resulted in one of the longest-lasting *Salmonella* outbreaks in Germany in recent years.

In the slaughterhouse, our recommendations to prevent introduction of *Salmonella* by pigs and cross-contamination of carcasses were implemented in September and October 2013. The last cases were reported in October, and the outbreak was declared over on 26 October 2013 after 6 days without any new cases (twice the maximum incubation time of salmonellosis). However, between 14 December 2013 and 26 May 2014, 13 additional cases of *S.* Infantis PT29 infection were notified to the local health authorities within the former outbreak region. Raw pork sausages from a butcher's shop with pork supplied by the implicated slaughterhouse tested positive for *S.* Infantis. Thus, the source of the *Salmonella* contamination in the slaughterhouse still seemed to be present at that time, but environmental investigations did not reveal any positive results. No further cases were reported after May 2014.

CONCLUSIONS AND RECOMMENDATIONS

In conclusion, we describe a large and prolonged outbreak of *S.* Infantis with 267 cases in central Germany in 2013. Combined efforts of epidemiologists, microbiologists, and health and food safety authorities identified raw pork products as the source of the outbreak. Elderly persons and persons using gastric acid-suppressant medications were the main affected patient groups. Insufficient hygiene measures in a slaughterhouse were the most probable cause of the persistent contamination of pork.

For rapid identification and interruption of the routes of contamination, it is necessary to have strong leadership involved in outbreak management and to rapidly implement control measures.

On the basis of our findings, we recommend for the prevention of salmonellosis that (1) immunocompromised persons (e.g. the elderly) and persons taking gastric acid-suppressant medications should refrain from consuming raw pork products, especially raw minced pork, (2) hygiene standards and process controls in the slaughterhouses are optimized and maintained, (3) the communication between health and food safety authorities should be strengthened by regular meetings or teleconferences in general, and particularly during outbreak investigations, and (4) local as well as state authorities should be included in relevant communication.

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DECLARATION OF INTEREST

None.

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