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Outbreak of *Salmonella enterica* serotype I 4,5,12:i:- infections: the challenges of hypothesis generation and microwave cooking

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SUMMARY

We investigated an outbreak of 396 *Salmonella enterica* serotype I 4,5,12:i:- infections to determine the source. After 7 weeks of extensive hypothesis-generation interviews, no refined hypothesis was formed. Nevertheless, a case-control study was initiated. Subsequently, an iterative hypothesis-generation approach used by a single interviewing team identified brand A not-ready-to-eat frozen pot pies as a likely vehicle. The case-control study, modified to assess this new hypothesis, along with product testing indicated that the turkey variety of pot pies was responsible. Review of product labels identified inconsistent language regarding preparation, and the cooking instructions included undefined microwave wattage categories. Surveys found that most patients did not follow the product's cooking instructions and did not know their oven's wattage. The manufacturer voluntarily recalled pot pies and improved the product's cooking instructions. This investigation highlights the value of careful hypothesis-generation and the risks posed by frozen not-ready-to-eat microwavable foods.

Key words: Food safety, foodborne infections, outbreaks, *Salmonella enterica*.

INTRODUCTION

Consumption of prepackaged frozen microwavable products has increased in recent decades, mirroring consumers' desire for easy to prepare meals [1]. Over 90% of homes in the USA have a microwave oven [2]. These devices offer convenience, but heat food unevenly [3–8]. This is of particular concern for frozen microwavable not-ready-to-eat (NRTE) products that require complete cooking for safe consumption [2, 3, 9, 10]. Salmonellosis outbreaks associated with foods prepared in microwave ovens have been reported since 1994 [11, 12]. A series of salmonellosis outbreaks caused by raw, frozen, microwavable chicken products demonstrated the outcome of consumers being unaware that a product is NRTE [9, 13, 14]. Even if

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they do understand that a product should be cooked and not just warmed, they may find it difficult to do so reliably.

On 6 June 2007, the Pennsylvania Department of Health reported a cluster of four *Salmonella enterica* serotype I 4,5,12:i:- infections since 11 May 2007 with indistinguishable pulsed-field gel electrophoresis (PFGE) patterns to PulseNet, the national subtyping network for foodborne disease surveillance [15]. The cluster grew as other states reported cases. The 40 isolates with this PFGE pattern reported to PulseNet in June 2007 represented a sixfold increase over the number reported in June 2006. We investigated the outbreak, and implicated contaminated frozen pot pies, a type of savoury pie completely encased by a flaky crust, as the source [16].

We describe the outbreak investigation, which highlights the importance of hypothesis generation.

METHODS

Case finding

Typically only *Xba*I restriction endonuclease digests of isolates are performed for PulseNet *Salmonella* surveillance. However, sometimes *Bln*I digests are also performed [17]. Because the outbreak *Xba*I pattern (pattern JPXX01·0206) was relatively common, we assessed *Bln*I patterns for additional discrimination. One (JPXA26·0180) of 18 *Bln*I patterns observed accounted for 89% of isolates. A case was defined as infection with a *Salmonella* strain exhibiting both JPXX01·0206 and JPXA26·0180 patterns in a person with illness onset during 28 April–31 December 2007. We asked public health laboratories to perform PFGE subtyping by *Xba*I on all serotype I 4,5,12:i:- and *S.* Typhimurium isolates (serotype I 4,5,12:i:- is a monophasic variant of serotype Typhimurium) and by *Bln*I in those exhibiting *Xba*I pattern JPXX01·0206. We monitored PFGE patterns that public health laboratories uploaded to PulseNet.

Hypothesis generation

During 26 June–3 October 2007, we used multiple methods to collect exposure information from case-patients: (1) routine state-specific case interviews, (2) standard hypothesis-generating questionnaires administered by state and local health departments and the Centers for Disease Control and Prevention (CDC), (3) in-person, open-ended interviews with four patients living in Hawthorne, Nevada (population 3111), and (4) routine Minnesota Department of Health practice of promptly interviewing all reported *Salmonella* case-patients with a detailed exposure form and using an iterative approach for investigating *Salmonella* PFGE subtype clusters. The Minnesota questionnaire contains exposure questions, including open-ended food histories (free recall of foods consumed during breakfast, lunch, dinner, and other meals during the 5 days before diarrhoea onset, with prompting to consider foods consumed at or outside of home), objective yes/no questions about specific food items, and brand, variety, and purchase location information for reported foods. Suspicious exposures identified during initial interviews are added, along with several similar exposures, to the standard interview for subsequent cases. Similarly, case-patients interviewed earlier in the investigation are re-interviewed to ensure uniform ascertainment of suspicious exposures [18]. We also queried PulseNet and VetNet for all isolates with the outbreak PFGE patterns from foods or animals [19].

Case-control study

On 3 October, a multi-state case-control study was initiated. Eligible case-patients were persons aged $\geqslant 2$ years whose illness began during 1 August–3 October, and had no ill contacts during the 2 weeks before illness. Some patients enrolled in the study had previously been interviewed for hypothesis-generation purposes. Age- and neighbourhood-matched controls were identified using an internet-based telephone directory. Investigators called telephone numbers until 1–3 persons of the appropriate age group with no diarrhoea during the previous 2 weeks agreed to complete an interview (or had caregivers willing to respond on their behalf). The exposure periods queried were 1 week before illness onset for patients and 1 week before interview for controls. We performed exact conditional logistic regression to examine exposures [20].

Pot pie exposure and cooking surveys

After the case-control study confirmed an association with pot pies, we administered another questionnaire by telephone to all consenting case-patients throughout the country. The questionnaire covered exposure to the implicated pot pies and related frozen foods. Persons who reported consumption of the implicated products within 7 days before illness were asked additional questions regarding the type of oven

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(conventional or microwave) used, its wattage, and adherence to the cooking instructions.

Laboratory investigation

Unopened brand A pot pies collected from patients' homes and from stores were cultured for *Salmonella* at state public health and department of agriculture laboratories and the University of Georgia's Center for Food Safety. *Salmonella* isolates were serotyped and subtyped by PFGE.

A subset of isolates from pot pies and patients was sent to CDC for serotyping and multiple-locus variable-number tandem repeat analysis (MLVA) [21]. Because we observed two primary MLVA patterns, we performed an *in vitro* serial passage experiment with one isolate of each primary pattern to assess stability of MLVA patterns over time. Each isolate was passed 20 times and 10 colonies were sampled from the baseline (pass 0) and at passages 5, 10, 15, and 20.

Environmental investigation

The United States Department of Agriculture's Food Safety and Inspection Service (FSIS) conducted trace-back and environmental investigations. Independent environmental testing was performed by company A.

RESULTS

Case-finding

During the outbreak period, 396 cases were reported from 41 states. Illnesses began between 28 April and 11 December 2007. The epidemic curve suggests three phases of disease transmission: an initial small peak in cases (phase 1), an interval of reduced case counts (phase 2), and a second large peak (phase 3). We define the five cases occurring before the start of sustained transmission on 28 April as background cases (Fig. 1).

The median age of patients was 20 years (range 1 month to 97 years); 50% were female. Of patients with available information, 317 (97%) of 326 had diarrhoea, 144 (50%) of 289 had bloody diarrhoea, and 108 (32%) of 338 were hospitalized. Health departments reported three deaths.

Hypothesis generation

Initial review of state-specific case investigations did not reveal a likely vehicle. Beginning on 14 August, 7 weeks were spent interviewing case-patients using a variety of methods (Fig. 2). The only common exposure among the four residents of Hawthorne, Nevada was dining at restaurant A, where one case-patient was a food service worker and where recent inspections identified potential for cross-contamination of foods by raw poultry. The most frequently reported food exposures identified nationally through questionnaires were chicken (71%), ground beef (65%), and eggs (59%). The VetNet database contained two records from 2007 of isolates with the outbreak PFGE patterns, both from chicken.

On 3 October, Minnesota epidemiologists learned that one patient had consumed brand A pot pies every day for lunch in the week before illness. They considered this exposure suspicious and added it, along with questions regarding other frozen foods, to their standard interview. The following day, exposure to brand A pot pies was reported by both a newly interviewed patient and a previously interviewed patient who was called back to be asked about pot pie consumption. That evening, Minnesota notified CDC and other states of these findings and exposure to brand A pot pies was subsequently confirmed in additional case-patients in three other states. On 5 October specific questions about pot pie consumption were added to the case-control study questionnaire.

Case-control study

We enrolled 17 case-patients and 24 matched controls residing in 10 states. Case-patients were more likely than controls to have eaten any variety of brand A pot pies [12 (71%) of 17 *vs.* 0 of 24, matched odds ratio 23·6, 95% confidence interval 3·8–∞). Establishment A produced three varieties of brand A pot pies: beef, chicken, and turkey. Of the 12 patients who reported consumption of brand A pot pies, the varieties reported were: turkey ($n=5$), chicken ($n=2$) and multiple varieties ($n=5$). None of the remaining 67 exposures evaluated were associated with illness.

Product description

Company A produced all brand A pot pies and eight additional brands of identical pot pies on a single production line at establishment A. The cooking instructions required persons to know the wattage category (low, medium, high) of the microwave oven, but did not provide definitions for these categories.

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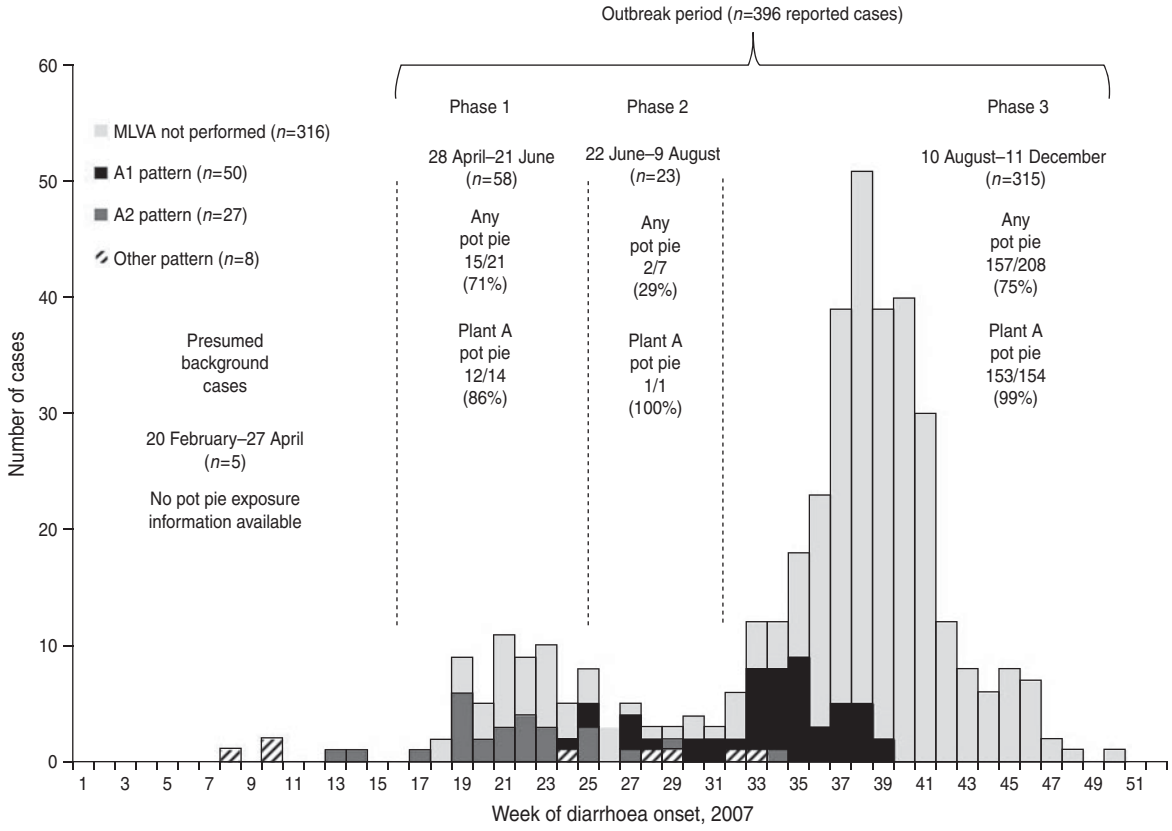

Fig. 1. Outbreak cases of *Salmonella* I 4,5,12:i:- infection by week of illness onset, MLVA pattern, and proportion of patients interviewed who reported consumption of any frozen microwavable pot pie and any such pot pie produced in establishment A by phase of outbreak – USA, 2007 ($n = 396$). The denominator for consumption of establishment A pot pies is restricted to patients who reported any pot pie and reported brand information. For 336 cases with complete information, the median duration from illness onset to date of culture was 3 days. For 65 cases with missing data, we estimated the date of illness onset as being 3 days before the date of culture.

A label on the front of the product stated, 'ready in 4 minutes'. The instructions required longer cooking times (6 min) for low-wattage ovens and also required the product to stand for 3 min after microwaving (Fig. 3).

Pot pie exposure survey

Of 236 case-patients interviewed, 174 (74%) reported consuming a frozen NRTE pot pie during the week before illness onset. Of 169 patients who provided brand information, 155 (92%) said they ate brand A, three (2%) either brand A or another brand produced at establishment A, eight (5%) either brand A or a brand not produced at establishment A, and three (2%) a brand not produced at establishment A. Of the 155 patients who reported consuming only brand A, 142 (92%) provided information on the likely type of pot pies consumed; 105 reported chicken, 100 reported turkey, and 23 reported beef. A similar frequency of pot pie consumption was observed in case-patients with illness onsets during phases 1 (71%) and 3 (75%) (Fig. 1).

Cooking survey

We surveyed 133 patients who reported consumption of a pot pie produced at establishment A about cooking practices; 102 (77%) cooked pies in a microwave oven. Of 78 patients who used a home microwave oven, 29% reported knowing the exact wattage and 42% reported knowing the wattage category. No patients reported using a low-wattage oven. Of eight patients who used a microwave oven outside the home, one (13%) reported knowing the wattage. Forty-eight (68%) of 71 who responded did not let pies stand the full recommended time after microwaving, and 16 (19%) of 84 patients cooked more than one pie simultaneously.

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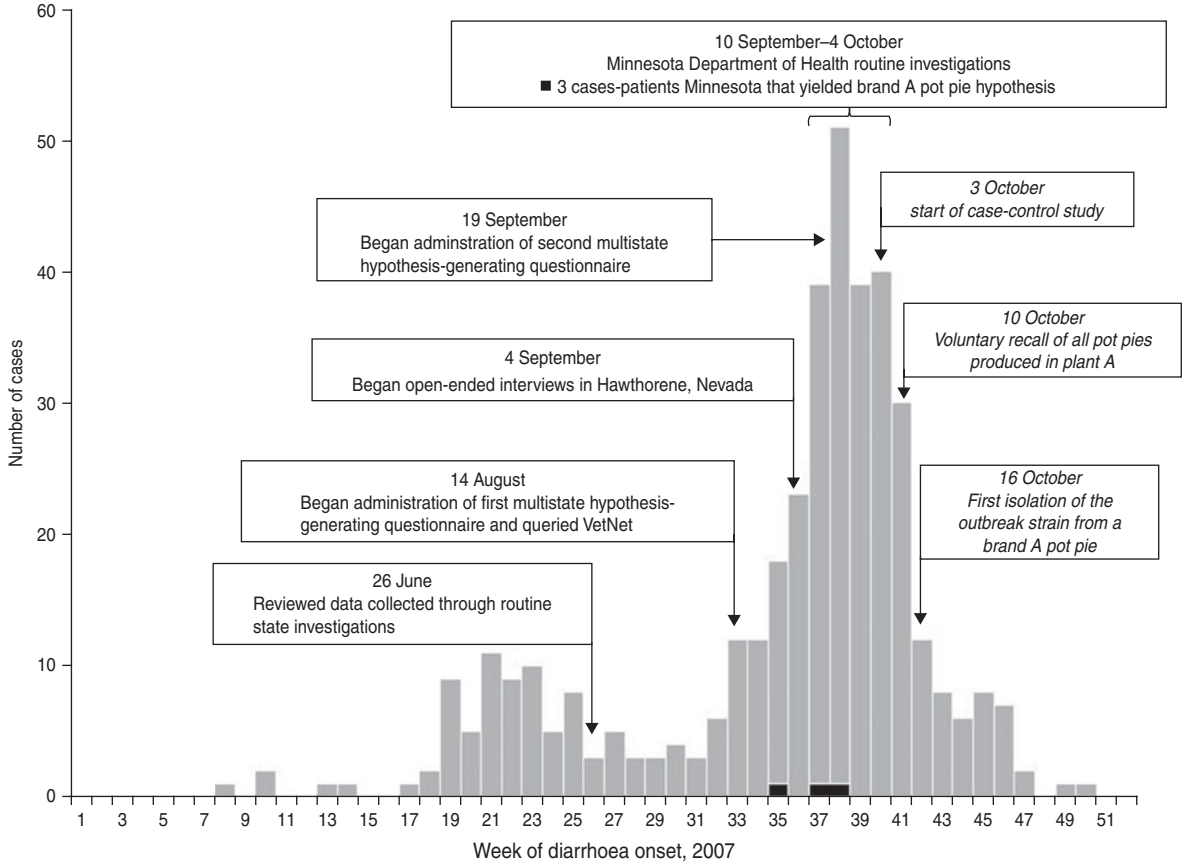

Fig. 2. Timeline of hypothesis-generation activities (shown in black outlined boxes). Because of reporting delays, the number of cases identified at the start of each activity was less than is indicated in this complete epidemic curve. The three case-patients whose interviews led to the brand A pot pie hypothesis are indicated by the black bars. Other key time points are indicated in the grey outlined boxes.

Product testing

Ninety-three brand A pies were tested: 50 chicken, 35 turkey, six beef, and two of unknown type; production dates ranged from 21 February–7 September 2007. *Salmonella* with the outbreak PFGE patterns was isolated from 14 turkey pies. All positive pies were produced on 13 July ($n=8$) or 31 July 2007 ($n=6$) (Fig. 4). Two pies underwent separate testing of the crust and filling; the filling of both pies yielded *Salmonella* isolates with the outbreak PFGE patterns and both crusts tested negative. Isolates from seven pies underwent MLVA, all had pattern A1.

Strain characterization

We confirmed all 80 human *Salmonella* isolates with the outbreak PFGE patterns received at CDC as *Salmonella* serotype I 4,5,12:i:-. Fifty (63%) isolates displayed MLVA pattern A1; this pattern was observed primarily during phases 2 and 3. The second most common pattern, A2, accounted for 25 (31%) isolates and was observed primarily in isolates from phase 1 (Fig. 1). Patterns A1 and A2 differed by two repeats at one of seven loci. One each of the five remaining isolates were classified as MLVA patterns A3, A4, C, D, and E. Patterns A3 and A4 both differed from pattern A1 by one repeat at one locus. The three non-A series patterns differed from the A series patterns at three loci by one or more repeats. Pot pie exposure information was unavailable for many patients with infections of known MLVA type, especially those with pattern A2 infections. Of patients with data available, a similar percentage of patients with A1 and A2 infections reported consumption of frozen pot pies (67% and 78%, respectively) (Table 1). During our *in vitro* stability study, both patterns remained stable.

Environmental findings

Four main ingredients entered establishment A for turkey and chicken pot pie production: raw

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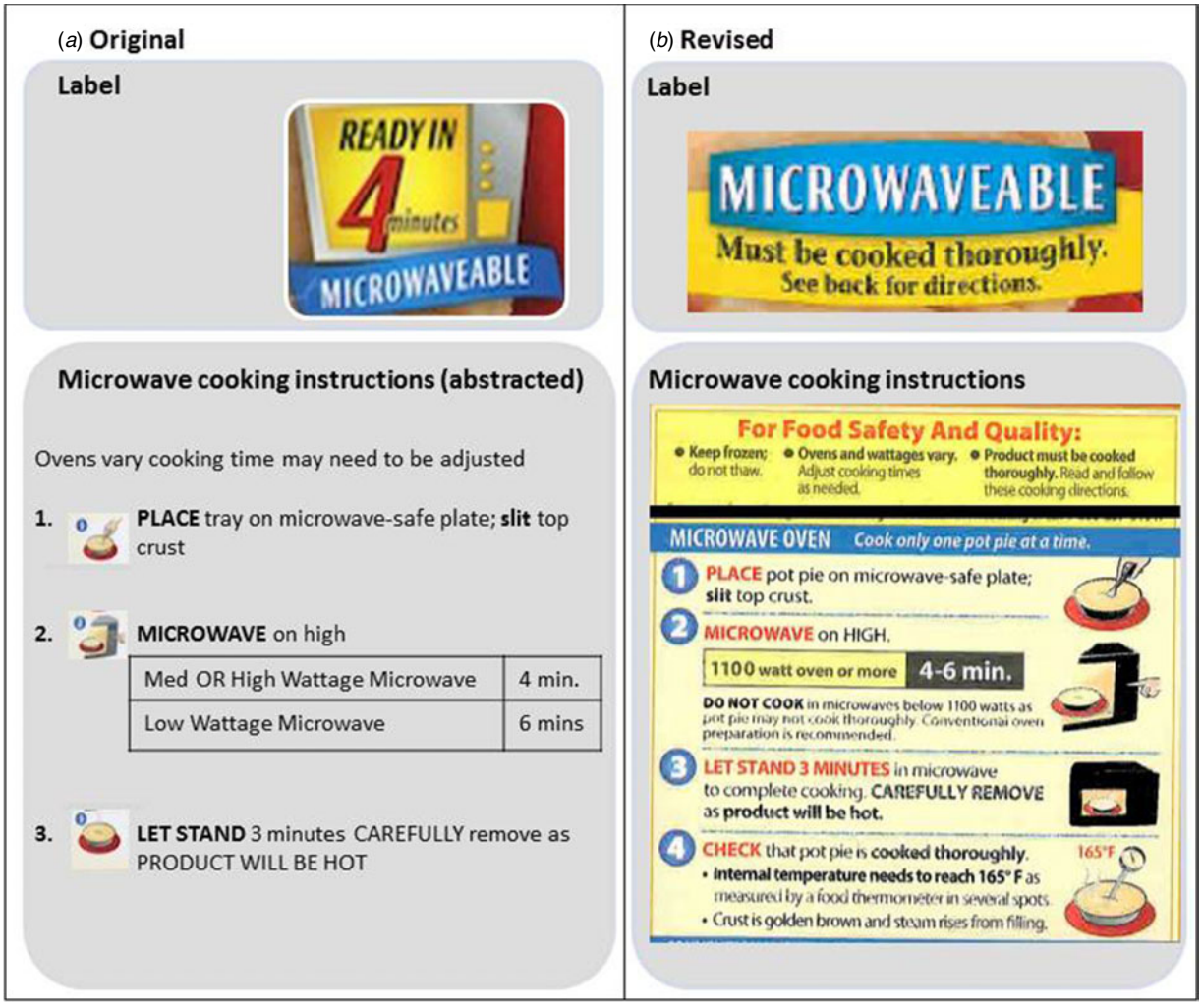

Fig. 3. Brand A pot pie package label and microwave cooking instructions. Panel (*a*) displays the text on the product box before and during the outbreak. Panel (*b*) displays the text on the product box after packaging was revised as a result of this outbreak.

flour, pre-blanched frozen vegetables, pre-cooked rolls of chicken and turkey meat, and raw frozen mechanically separated chicken and turkey. Establishment A workers diced the pre-cooked meat and heated the raw mechanically separated poultry products to $\geqslant 82{\cdot}2\,^{\circ}C$ to form, along with the vegetables, the filling of the pies. The final pie contained a raw flour crust. Blanched potatoes were the only ingredient in which the same production lot was used on both 13 and 31 July 2007; the establishment used the same lot on other days as well.

Company A reported that all independent ingredient and environmental testing was negative. Ingredients used on 13 or 31 July 2007 were not available for testing, and no raw mechanically separated chicken and turkey was tested. FSIS performed environmental testing at five facilities supplying pre-cooked meat and poultry to establishment A; all testing was negative.

FSIS identified inadequate documentation to support company A's decisions regarding hazard analyses for incoming materials and validation of cooking instructions on their labels. The equipment used to heat the mechanically separated poultry included a temperature display. Company A periodically assessed the accuracy of the displayed temperature by using a second thermometer. On review of company A records, FSIS noted that on 4 days during July–September 2007 the temperature measured by the second thermometer was lower than the temperature on the primary display by more than 5 °F (about 2·8 °C), but never read $<76{\cdot}7\,^{\circ}C$, and mostly read $>93{\cdot}3\,^{\circ}C$. The critical limit temperature was $\geqslant 71{\cdot}1\,^{\circ}C$, which is in compliance with FSIS/USDA regulations

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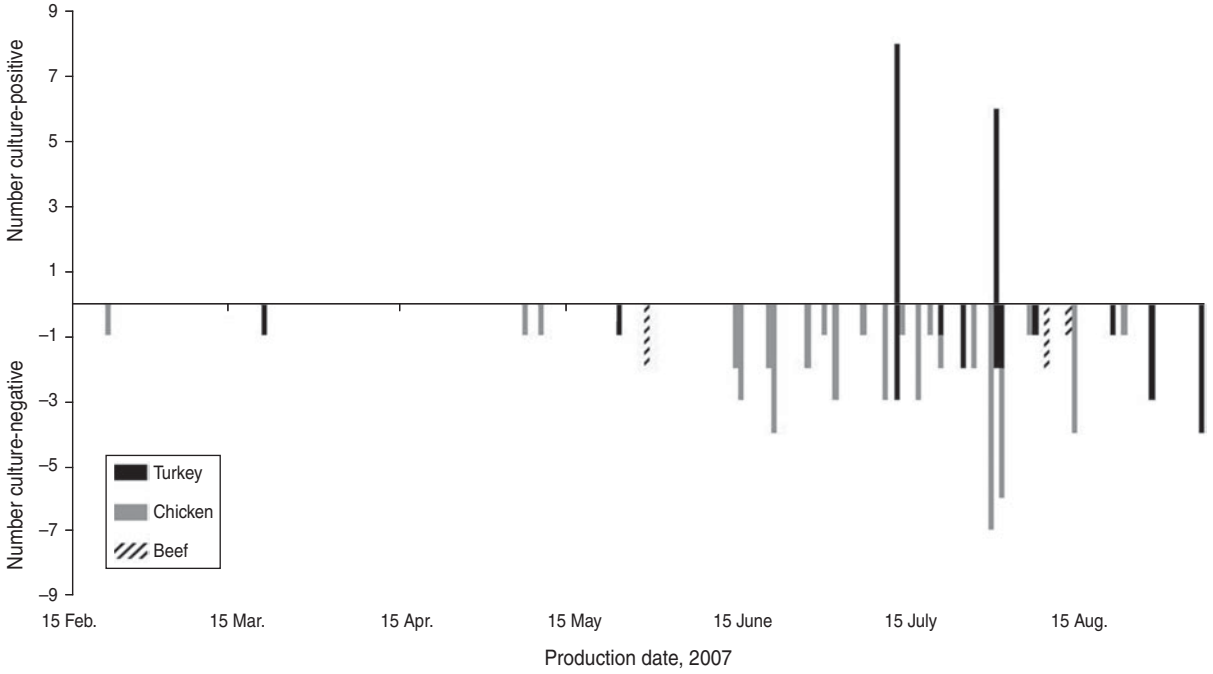

Fig. 4. Culture results of 89 brand A pot pies by date of pie production and type of meat. Y-axis indicates the number of pies positive or negative for *Salmonella* with the outbreak PFGE patterns. The figure does not include two brand A pot pies of unknown meat variety and two brand A pot pies produced before 2007.

[22]. However, the establishment lacked appropriate physical barriers between the area in which heating of mechanically separated poultry occurred and the rest of the establishment.

Public health measures

On 8 October 2007, company A stopped production at establishment A. On 9 October, CDC and FSIS issued advisories not to eat poultry-containing pies produced in establishment A. On 10 October, both agencies expanded advisories to include beef-containing pies because many patients could not recall the exact type of brand A pie consumed. As such, company A issued a voluntary recall of all nine brands of pies produced in establishment A. Before resuming production, the manufacturer improved the wording of prominent product labelling, making it consistent with cooking instructions and clearly indicating the need for thorough cooking. Improvements made to instructions included: (1) restricting microwave cooking to microwave ovens of $\geqslant$1100 W, (2) indicating that the post-microwave stand time is needed to complete cooking, (3) adding a final step of assessing for signs of complete cooking which includes use of a thermometer, and (4) specifying cooking of only one pie at a time (Fig. 3).

DISCUSSION

We described a multistate salmonellosis outbreak associated with contaminated frozen NRTE pot pies, a novel food vehicle. The outbreak highlights the importance of effective hypothesis generation. Our findings suggest that this outbreak was caused, in part, by the microwavable nature of the products. Many, but not all, patients prepared the pies in microwave ovens. The product's labelling and microwave cooking instructions were inconsistent and unclear. Many patients did not follow the instructions.

Previous frozen NRTE foods identified as vehicles of outbreaks and sporadic illnesses all contained raw poultry [9, 13, 14]. The products were breaded or pre-browned, causing many people to believe that they were precooked. The pot pies in the outbreak described here were the first recognized frozen microwavable NRTE food vehicles that contained only ready-to-eat (fully cooked) meat or poultry. They were NRTE because of their raw flour crusts. It is plausible that contaminated flour was the source of contamination. In North America, 0·14% of wheat flour samples test positive for *Salmonella* and flour has been implicated in an outbreak of *S.* Typhimurium infections [23, 24]. A more likely source was raw mechanically separated poultry that may not have been sufficiently cooked at establishment A, or that

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Table 1. *Multiple-locus variable-number tandem repeat analysis (MLVA) by phase of outbreak, reported exposure to any frozen pot pies, and reported exposure to frozen pot pies produced in establishment A*

	Phase 1			Phase 2			Phase 3			Phases 1, 2, and 3		
MLVA pattern	All cases *n*	Any frozen pot pie *n* (%)	Estab. A pot pie *n* (%)	All cases *n*	Any frozen pot pie *n* (%)	Estab. A pot pie *n* (%)	All cases *n*	Any frozen pot pie *n* (%)	Estab. A pot pie *n* (%)	All cases *n*	Any frozen pot pie *n* (%)	Estab. A pot pie *n* (%)
A1	2	0/1 (0)	–	9	0/3 (0)	–	39	22/29 (76)	21/21 (100)	50	22/33 (67)	21/21 (100)
A2	22	7/9 (78)	5/6 (83)	2	–	–	1	–		25	7/9 (78)	5/6 (83)
A3 or A4	0			1	–	–	1	1/1 (100)	1/1 (100)	2	1/1	1/1 (100)
Non-A series	1	–	–	1	0/1 (0)	–	1	1/1 (100)	–	3	1/2 (50)	–
Unknown	33	8/11 (73)	7/8 (88)	10	2/3 (66)	1/1 (100)	273	133/177 (75)	131/132 (99)	316	143/191 (75)	139/141 (99)
Total*	58	15/21 (71)	12/14 (86)	23	2/7 (29)	1/1 (100)	315	157/208 (75)	153/154 (99)	396	174/236 (74)	166/169 (98)

Estab. A, Establishment A.
Eight patients who reported consumption of a pot pie produced either in establishment A or a brand not produced at establishment A were classified as exposed to an establishment A pot pie.
* The denominator for consumption of establishment A pot pies is restricted to patients who reported eating any pot pie and reported brand information.

cross-contaminated the pies, either by contact with other components of the pie or by inadvertent inclusion as an ingredient. Raw US poultry is frequently contaminated with *Salmonella* [25]. In 2010, serotype I 4,5,12:i:- was equal with two other serotypes as the seventh most common *Salmonella* serotype isolated from chicken breasts purchased from retail stores and it was the sixth most common serotype isolated from chickens at time of slaughter [26, 27].

This outbreak spanned 7 months and involved three phases. Phase 3 was the largest and the only phase included in the case-control study. At least two contamination events of pot pies with the A1 MLVA pattern, on 13 and 31 July, led to phase 3. Phase 1 illnesses were caused mainly by the A2 MLVA pattern. Although no isolates from pies had this pattern, food exposure data suggest that brand A pies (or other brands produced in establishment A) were the vehicle, with the contamination event most likely in April 2007. We had limited ability to detect this event because only two pies produced before or during April 2007 were tested. The relationship of phase 2 illnesses to pot pies is unknown. The seven patients interviewed from this time period had a low exposure frequency to pot pies. This suggests that background cases (i.e. not related to pot pie consumption) may have contributed a greater proportion of phase 2 cases compared to phases 1 and 3.

The *in vitro* stability of A1 and A2 strains supports the occurrence of separate contamination by two genetically very similar strains. If contamination was introduced in the establishment through raw poultry and this strain and its variants are endemic in poultry, it is plausible that a poultry lot used in April was contaminated with one variant, and that one or more lots used in July from the same source were contaminated with another variant.

This investigation highlights the importance of hypothesis-generation methods. A well refined hypothesis was not formed until the Minnesota Department of Health identified brand A pot pies as a possible vehicle based on interviews with three patients, over 7 weeks into the investigation. Had Minnesota investigators not identified brand A pot pies, considerable resources would have been spent in an unsuccessful case-control study because this exposure would not have been included as part of the questionnaire. Reasons for delays in identifying this vehicle probably included the following: a relatively small proportion of patients interviewed; an absence of detailed and specific food exposure information, such as product brands,

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collected during early interviews; difficulty in detecting specific exposures shared by patients because interviews were conducted by multiple interviewers in different agencies making the identification of exposure details not on the questionnaire unlikely; interviewers' varying degrees of experience in foodborne illness cluster investigations; delays between illness and interview; and the considerable portion of interviews conducted on patients who were ill during phase 2 of the outbreak, including all three patients in Hawthorne, Nevada with phase 2 illnesses (all denied exposure to pot pies). Sixteen patients, excluding those from Minnesota and Hawthorne, Nevada, whose hypothesis-generation interviews did not elicit pot pie exposure were re-interviewed about pot pies. On re-interview, nine patients reported having consumed brand A pies, one was unsure, two reported different brands, and four denied exposure.

The Minnesota iterative cluster investigation approach interviews patients as soon as they are reported, thus reducing the delay from illness onset to detailed exposure assessment, and involves a single experienced interviewing team, which allows rapid evaluation of suspicious exposure findings [18]. A similar approach is now being evaluated in seven other locations of the FoodCORE programme [28]. This approach may be less feasible in places with decentralized investigation of enteric illness where local public health officials often conduct the interviews. Although re-interviewing patients about suspicious exposures could, in theory, introduce bias if patients suspect the exposure is a leading hypothesis, the iterative interviewing method has not been observed to falsely incriminate a food vehicle because of the following measures: (1) asking about a variety of exposures during the re-interview; (2) requiring the strength of cumulative evidence be large enough that the observed association is unlikely an artifact of bias; (3) assessing biological plausibility; and (4) ensuring geographical distributions of the food and cases are compatible.

Although the standard questionnaire chosen for early hypothesis-generation interviews by all states in this outbreak closely resembled the questionnaire used by Minnesota, most interviewers did not collect any information in the open-ended free recall exposure sections and most questions that collected exposure details (e.g. product brands, place of purchase) were left unanswered. Incomplete exposure information may have been a result of interviewing technique, long delays from time of illness to interview, or both.

Features of microwave cooking may increase the risk of foodborne illness [4]. Microwaves are non-ionizing electromagnetic waves that cause polar molecules to rotate, and, thereby, heat foods through molecular friction. Most studies find that pathogen destruction is mediated by heat [4, 29, 30]. Compared to a conventional oven, ensuring thorough cooking in microwave ovens is more difficult because of wattage variability and uneven heating [4, 30]. The true power, or wattage, of a microwave oven can vary by 20% depending on the voltage of electricity operating the appliance [30]. Furthermore, wattage output can be reduced by up to 20% if the oven operates longer than several minutes [30].

Microwaves cook foods unevenly. Temperatures 1 cm apart in a food item may differ by >20 °C [4]. Many factors influence the uniformity of final temperatures, including the shape of the oven cavity and food, the location of the food in the oven, and the composition of the food [4, 30–33]. Therefore, most instructions for microwavable NRTE foods require cooks to allow the food to stand for several minutes after cooking or to stir or turn the food during or after cooking so that heat is more equally distributed to minimize cold spots that could harbour pathogens [34]. However, we found that most patients interviewed about cooking practices did not allow pies to stand the full recommended time. Another outbreak investigation found that many ill persons did not turn products as instructed [9].

Oven temperature and cooking time, both of which can be controlled by people preparing meals, are the primary factors for cooking completeness in traditional ovens. Similarly, the main factors that affect completeness of cooking in microwave ovens are wattage and time. Because wattage is typically not adjustable and because, at the time of this outbreak, the manufacturer's stated wattage was not visible on most ovens, persons cooking these NRTE products in microwave ovens had to guess the wattage to follow the instructions. We, like other investigators [9], documented that most patients could not report the wattage of the oven used. Furthermore, we identified unclear cooking instructions on brand A pot pie packaging referring to 'low', 'medium', and 'high' wattage ovens. Because of the absence of established wattage thresholds defining these categories, cooking instructions should refer to specific wattages, similar to the revised brand A cooking instructions (Fig. 3). Consumers can estimate their oven's actual wattage output using a simple procedure [35].

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Following this outbreak, the industry took important steps to make microwavable NRTE foods safer. First, some retailers now require that the wattage be clearly labelled on the microwave ovens they sell [31]. Second, the food industry established guidelines for developing validated cooking instructions and clearly written instructions and product labelling [2, 10]. Third, a collaborative consumer education campaign by industry and government, 'Cook it Safe', aims to disseminate four messages: (1) follow package cooking instructions; (2) know when to use a microwave or conventional oven; (3) know your microwave wattage; and (4) always use a food thermometer to ensure a safe internal temperature [36].

It is unknown whether these efforts will reduce the risks associated with frozen, microwavable NRTE products. Outbreaks associated with these products have continued to occur. In 2010, an outbreak of *Salmonella* infections was linked to a chicken-containing entrée [37]. The consumer's focus on convenience could limit the impact of educational campaigns. The ultimate solution may be to pre-cook all foods marketed as microwaveable, or to use new microwave oven technologies that reduce the risk of uneven cooking.

This investigation underscores the importance of coupling laboratory-based surveillance of foodborne infections at the molecular subtype level with interviewing of patients in an iterative manner by skilled interviewers to detect, solve, and truncate outbreaks. Public health officials should consider frozen microwavable NRTE products during outbreak investigations.

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DECLARATION OF INTEREST

None.

REFERENCES

1. **Park JL, Capps O.** Demand for prepared meals by US households. *American Journal of Agricultural Economics* 1997; **79**: 814–824.
2. **Allan J.** Cooking food safely with microwave ovens: challenges for the food industry. *Food Protection Trends* 2009; **29**: 77–79.
3. **Huang L, Sites J.** New automated microwave heating process for cooking and pasteurization of microwaveable foods containing raw meats. *Journal of Food Science* 2010; **75**: E110–E115.
4. **Heddleson RA, Doores S.** Factors affecting microwave-heating of foods and microwave-induced destruction of foodborne pathogens – a review. *Journal of Food Protection* 1994; **57**: 1025–1037.
5. **Farber JM, *et al.*** Survival of *Listeria* spp. on raw whole chickens cooked in microwave ovens. *Journal of Food Protection* 1998; **61**: 1465–1469.
6. **Levre E, Valentini P.** Inactivation of salmonella during microwave cooking. *Zentralblatt für Hygiene und Umweltmedizin* 1998; **201**: 431–436.
7. **Lindsay RE, Krissinger WA, Fields BF.** Microwave vs. conventional oven cooking of chicken: relationship of internal temperature to surface contamination by *Salmonella* typhimurium. *Journal of the American Dietetic Association* 1986; **86**: 373–374.
8. **Lund BM, Knox MR, Cole MB.** Destruction of *Listeria monocytogenes* during microwave cooking. *Lancet* 1989; **1**: 218.
9. **Smith KE, *et al.*** Outbreaks of salmonellosis in Minnesota (1998 through 2006) associated with frozen, microwaveable, breaded, stuffed chicken products. *Journal of Food Protection* 2008; **71**: 2153–2160.
10. **Hontz L, Scott V, Chen Y.** Assuring the safety of not-ready-to-eat (NRTE) products: industry guidelines for validation of consumer cooking instructions. *Food Protection Trends* 2009; **29**: 72–76.
11. **Gessner BD, Beller M.** Protective effect of conventional cooking versus use of microwave ovens in an outbreak of salmonellosis. *American Journal of Epidemiology* 1994; **139**: 903–909.
12. **Evans MR, Parry SM, Ribeiro CD.** Salmonella outbreak from microwave cooked food. *Epidemiology and infection* 1995; **115**: 227–230.
13. **Kenny B, Hall R, Cameron S.** Consumer attitudes and behaviours – key risk factors in an outbreak of *Salmonella* typhimurium phage type 12 infection sourced to chicken nuggets. *Australian and New Zealand Journal of Public Health* 1999; **23**: 164–167.
14. **FSIS, USDA.** Issues public health alert for frozen, stuffed raw chicken products (http://www.fsis.usda.gov/News_&_Events/NR_100308_01/index.asp). Accessed 13 January 2012.
15. **Boxrud D, *et al.*** The role, challenges, and support of pulsenet laboratories in detecting foodborne disease

outbreaks. *Public Health Reports* 2010; **125** (Suppl. 2): 57–62.

16. **Centers for Disease Control and Prevention.** Multistate outbreak of salmonella infections associated with frozen pot pies – United States, 2007. *Morbidity and Mortality Weekly Report* 2008; **57**: 1277–1280.
17. **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.
18. **Rounds JM, *et al.*** *Salmonella enterica* pulsed-field gel electrophoresis clusters, Minnesota, USA, 2001–2007. *Emerging Infectious Diseses* 2010; **16**: 1678–1685.
19. **Jackson CR, *et al.*** Introduction to United States Department of Agriculture VetNet: status of salmonella and campylobacter databases from 2004 through 2005. *Foodborne Pathogens and Disease* 2007; **4**: 241–248.
20. **Mehta CR, Patel NR.** Exact logistic regression: theory and examples. *Statistics in Medicine* 1995; **14**: 2143–2160.
21. **PulseNet International.** Laboratory standard operating procedure for PulseNet MLVA of *Salmonella enterica* serotype Typhimurium – Beckman Coulter CEQ™ 8000 platform (http://www.pulsenetinternational.org/SiteCollectionDocuments/mlva/PNL21_MLVA_20Salm_20 T_20Beckman_20Protocol.pdf). Accessed 23 February 2012.
22. **FSIS, USDA.** Appendix A: Compliance guidelines for meeting lethality performance standards for certain meat and poultry products (http://www.fsis.usda.gov/oa/fr/95033F-a.htm). Accessed 14 August 2012.
23. **Sperber W.** Role of microbiological guidelines in the production and commercial use of milled cereal grains: a practical approach for the 21st century. *Journal of Food Protection* 2007; **70**: 1041–1053.
24. **New Zealand Food Safety Authority.** Flour batch believed linked to salmonella outbreak (http://www.foodsafety.govt.nz/elibrary/industry/Flour_Batch-Investigations_Into.htm). Accessed 6 January 2012.
25. **Naugle A, *et al.*** U.S. Food Safety and Inspection Service testing for salmonella in selected raw meat and poultry products in the United States, 1998 through 2003: analysis of set results. *Journal of Food Protection* 2006; **69**: 2607–2614.
26. **United States Food and Drug Administration.** 2010 Retail Meat Report: National Antimicrobial Resistance Monitoring System (http://www.fda.gov/downloads/AnimalVeterinary/SafetyHealth/AntimicrobialResistance/NationalAntimicrobialResistanceMonitoringSystem/UCM293581.pdf). Accessed 30 August 2012.
27. **USDA Bacterial Epidemiology and Antimicrobial Resistance Research Unit.** NARMS: 2010 Animal Arm Annual Report (http://ars.usda.gov/SP2UserFiles/Place/66120508/NARMS/NARMS2010/NARMS%20USDA%202010%20Report.pdf). Accessed 30 August 2012.
28. **Centers for Disease Control and Prevention.** Foodborne Diseases Centers for Outbreak Response Enhancement (http://www.cdc.gov/foodcore/about.html). Accessed 28 August 2012.
29. **Heddleson RA, Doores S, Anantheswaran RC.** Parameters affecting destruction of *Salmonella* spp. by microwave-heating. *Journal of Food Science* 1994; **59**: 447–451.
30. **Chen Y.** IAFP Timely Topics Symposium on prepared but not ready-to-eat-foods-what you need to know *Food Protection Trends* 2008; **12**: 201–203.
31. **Vlock S.** Food safety and the microwave (http://www.rippeinfoservices.com/conagra-foods-science-institute/webinars/pdf/FoodSafety112409.pdf). Accessed 16 January 2012.
32. **Heddleson RA, *et al.*** Viability loss of *Salmonella* species, *Staphylococcus aureus*, and *Listeria monocytogenes* in complex foods heated by microwave energy. *Journal of Food Protection* 1996; **59**: 813–818.
33. **Dealler SF, Lacey RW.** Superficial microwave heating. *Nature* 1990; **344**: 496.
34. **Heddleson RA, Doores S.** Injury of *Salmonella* species heated by microwave energy. *Journal of Food Protection* 1994; **57**: 1068–1073.
35. **FSIS, USDA.** Microwave ovens and food safety (http://www.fsis.usda.gov/Fact_Sheets/Microwave_Ovens_and_Food_Safety/index.asp). Accessed 18 January 2012.
36. **FSIS, USDA.** Consumers urged to 'Cook It Safe' when preparing convenience foods (http://www.fsis.usda.gov/News_&_Events/NR_090111_01/index.asp). Accessed 19 January 2012.
37. **Centers for Disease Control and Prevention.** Investigation update: multistate outbreak of human *Salmonella* Chester infections (http://www.cdc.gov/salmonella/chester/). Accessed 19 January 2012.
38. **Centers for Disease Control and Prevention.** Investigation of outbreak of human Infections caused by *Salmonella* I 4,[5],12:i:- (http://www.cdc.gov/salmonella/4512eyeminus.html). Accessed 16 August 2012.