Epidemic Giardiasis Caused by a Contaminated Public Water Supply

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Abstract: In the period November 1, 1985 to January 31, 1986, 703 cases of giardiasis were reported in Pittsfield, Massachusetts (population 50,265). The community obtained its water from two main reservoirs (A and B) and an auxiliary reservoir (C). Potable water was chlorinated but not filtered. The incidence of illness peaked approximately two weeks after the city began obtaining a major portion of its water from reservoir C, which had not been used for three years. The attack rate of giardiasis for residents of areas supplied by reservoir C was 14.3/1000, compared with 7.0/1000 in areas that received no water from reservoir C. A case-control study showed that persons with giardiasis were more likely to be older and to have drunk more municipal water than household controls. A community telephone survey indicated that over 3,800 people could have had diarrhea that might have been caused by *Giardia*, and 95 per cent of households were either using alternate sources of drinking water or boiling municipal water. Environmental studies identified *Giardia* cysts in the water of reservoir C. Cysts were also detected in the two other reservoirs supplying the city, but at lower concentrations. This investigation highlights the risk of giardiasis associated with unfiltered surface water systems. (*Am J Public Health* 1988; 78:139–143.)

Introduction

Waterborne giardiasis is becoming an important public health problem in the United States: during the period from 1965–84, 90 outbreaks and 23,776 cases of giardiasis were reported. Sixty-nine per cent of outbreaks and 74 per cent of cases related to contamination of public water supplies, the majority of which were surface water systems with inadequate filtration or chlorination.[1] We describe one of the largest waterborne outbreaks of giardiasis ever reported in the United States and highlight the risk of giardiasis in communities that are supplied by unfiltered surface water systems.

Background

The outbreak occurred in the western Massachusetts city of Pittsfield (population, 50,265, 1985 census). The problem was first recognized during the first week of December 1985, when the health department of Pittsfield received 70 reports of laboratory-confirmed giardiasis. Only 53 positive stool samples for *Giardia* had been submitted during the entire one-year prior to November 1, 1985. Interviews of the 70 case-patients revealed that they had negative stool cultures for bacterial enteric pathogens, no common personal contact, and they were widely distributed throughout the city. This information, coupled with the knowledge that a new reservoir had been added to the community water supply in November, led city and state health officials to suspect a waterborne outbreak of giardiasis.

Water Supply

Prior to November 1985, the community obtained its drinking water from two surface reservoirs, A and B. Water was chlorinated but not filtered. However, during November 1985, alterations were made to the water system to facilitate the construction of a filtration system for water originating from reservoir A. Specifically, on November 5, an auxiliary reservoir C was brought on line for the first time in over three years to replace water from reservoir A which was to be phased out while the filtration system was being installed. This was expected to be a temporary yet necessary step in order to meet the usual demand for water, as installation of filtration equipment for reservoir A required decreasing the flow of reservoir A water into the city's water system during the construction period. On November 14, as construction proceeded, the flow from reservoir C was increased and the flow from reservoir A was correspondingly increased. On this day, the water department received complaints of turbid water from many areas of the city; the increased turbidity was attributed to reversals in water flow which suspended sediment in the water mains. After approximately two days, the turbidity resolved spontaneously. Reservoir C supplied water to the city until December 21, when it was replaced by reservoir A.

Methods

Epidemiologic Investigation

Daily reports of positive *Giardia* isolates were obtained from the two clinical laboratories in the region. The investigators attempted to reach every reported case-patient by telephone; patients were asked to report demographic information and the onset date of symptoms. Local physicians were sent letters encouraging them to obtain stool analyses from patients with symptoms clinically consistent with giardiasis, and were urged to report positive cases to the local health department.

Laboratory analysis of stool samples were performed locally by the major clinical laboratory in the area. Stool samples were cultured for *Salmonella, Shigella,* and *Campylobacter.* Analysis for ova and parasites was performed using standard direct saline and formalin-ethyl acetate methods.[2]

A confirmed case of outbreak-associated giardiasis was defined as a Pittsfield resident with a stool sample positive for *Giardia lamblia* submitted after November 1, 1985. A suspect case of giardiasis was anyone interviewed in the community surveys who reported having had diarrhea (≥3 loose stools per 24-hour period) of undetermined etiology of ≥5 days duration with onset since November 1, 1985.

Information obtained from the city water engineer con-

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cerning placement of values in the municipal water system was used to construct a water distribution map depicting the reservoir origin of drinking water and the distribution pattern throughout the city between November 1, 1985 and January 31, 1986 (Figure 1). We estimated the population in each of these regions using census tract data obtained in March 1985; populations in areas that were included in more than one census tract data were divided in proportion to the length of city streets in each area. Attack rates were then determined for each water distribution area by counting the number of reported case-patients residing in each region divided by the estimated population.

Case-Household Telephone Survey

Questionnaires were administered by telephone to each of the first 139 reported case-patients during the first week of the investigation (December 13–19); each of these case-patients was asked to supply information about all household members. Whenever possible, all household members were interviewed individually. They were asked to describe their principal source of drinking water and the number of glasses of beverages containing both unboiled and boiled municipal water they customarily drank per day, as well as any gastrointestinal symptoms they may have experienced.

A case-control study was performed using the survey data to identify risk factors for giardiasis. Cases were defined as persons with laboratory-confirmed giardiasis; controls were defined as persons who did not have positive stool samples and had no diarrhea. Cases and controls were matched within households, and conditional logistic regression[3] was used to determine whether age and water consumption were independently associated with giardiasis.

Case Telephone Survey

Questionnaires similar to those used in the case-household survey were administered to the next 100 reported case-patients. Additional questions were included for these 100 persons specifically describing their consumption of municipal water at home and away from home. Information about household members was not obtained.

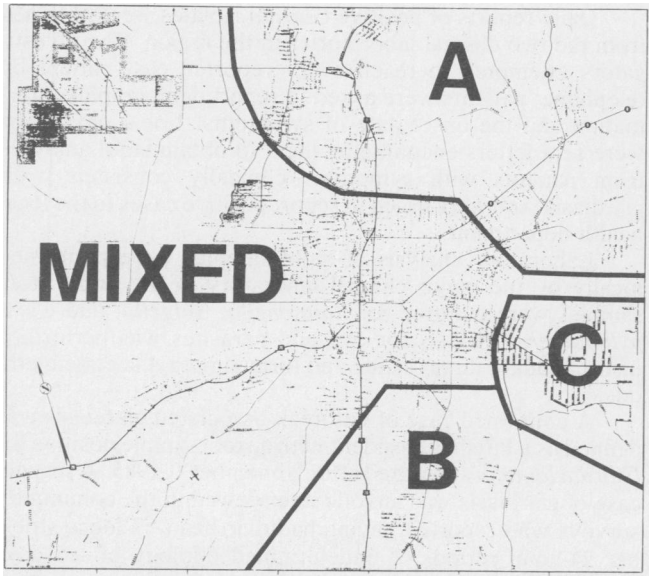


FIGURE 1—Water Distribution by Reservoir Source, Pittsfield, Massachusetts, November 1 to December 21, 1985

Community Telephone Survey

A community telephone survey of 220 households randomly selected from the telephone directory was conducted on January 16, 1986. The purpose of the survey was to determine whether laboratory reports of positive stool samples were true indicators of the occurrence of disease in the community. By this time, physicians may have been treating an increasing number of symptomatic patients empirically without having obtained stool samples because of the widespread publicity associating diarrhea with giardiasis. Each household member was to be interviewed concerning water consumption, gastrointestinal symptoms, diagnosis, and treatment. Heads of households were also asked about compliance with control measures. The systematic sampling technique was performed using methods described by Kish,[4] and 95% confidence intervals (CI) of estimated numbers of cases were determined using a method described by Mendenhall.[5]

Environmental Investigation

We reviewed all available water quality testing results indicating turbidity, coliform, and chlorine levels since January 1, 1985. Personnel from city and state environmental engineering agencies inspected the water distribution system for cross-connections with sewage lines.

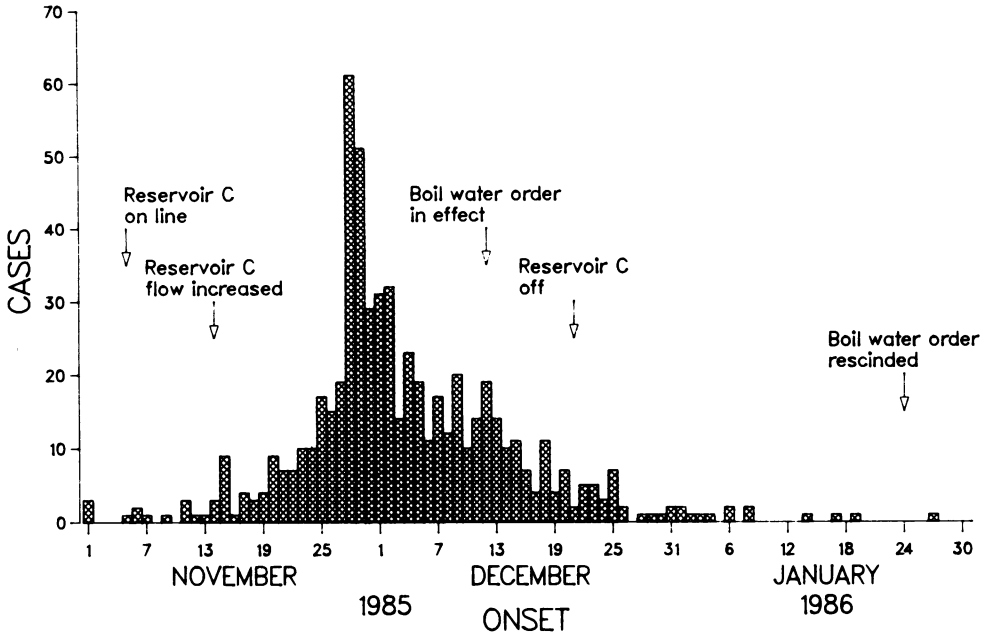
Chlorinated water from reservoir C immediately distal to the chlorination point was sampled for *Giardia* cysts on December 12; untreated water in all three reservoirs was sampled on December 16; additional samples were obtained from three sites in the distal portion of the distribution system on four occasions in late December and early January. Sampling for *Giardia* cysts was performed using volume-sampling orlon yarn filters supplied by the US Environmental Protection Agency (EPA).[6] Analysis of water samples for *Giardia* was also performed by the EPA using an immunofluorescent antibody technique.[7] *Giardia* cysts extracted from the water samples obtained from each of the three reservoirs were tested for infectivity by inoculation in gerbils.[8] *Giardia* trophozoites obtained from these animals were then examined at the University of Minnesota by scanning electron microscopy for morphological characteristics in order to determine whether they were from human or animal origin.

Inspectors surveyed the watershed areas of the three reservoirs for signs of sewage contamination and beaver activity in December 1985; beavers obtained during the survey were examined for *Giardia*. During the summer of 1986, muskrats were obtained from the watershed areas of all three reservoirs and examined for infection with *Giardia*.

Eleven outbreak-related human fecal samples were sent to the University of Minnesota for use in a cross-species transmission experiment. Beavers and muskrats were administered *Giardia* cysts from these samples and examined for infection. *Giardia* trophozoites obtained from these animals were also studied for morphological characteristics.

Results

From November 1, 1985 to January 31, 1986, 703 persons were identified with positive stool samples for *Giardia*. During this same period, approximately 2,600 persons submitted stool samples, yielding a *Giardia*-positive rate of 27 per cent. Onset dates of illness were obtained from 604 (86 per cent) of the 703 confirmed case-patients, and residential address was confirmed for 635 persons (90 per cent). The greatest number of persons reported onset of symptoms on



*604 stool-positive cases. Date of onset unknown for 99 cases.

FIGURE 2—Laboratory-confirmed Cases of Giardiasis, by Date of Onset, Pittsfield, Massachusetts, November 1, 1985 to January 31, 1986

November 28, two weeks after the flow from reservoir C was increased and the episode of turbid water occurred (Figure 2). When attack rates of laboratory-confirmed giardiasis were calculated by place of residence, the highest attack rates were found for areas of the city served by reservoir C (Table 1).

Case-Household and Case Telephone Surveys

In the case-household survey of 139 households, information was obtained about all 437 household members. Eight additional persons with positive stool samples, who had not yet been reported, were identified, yielding 147 confirmed case-patients. Of the next 100 case-patients who were interviewed in the case telephone survey, seven had been interviewed before in the case-household survey; thus, a total of 240 confirmed case-patients were interviewed in detail concerning their symptoms. Among these 240, 236 (98 per cent) had diarrhea. The mean duration of diarrhea was 11.3 days, with a range of 1–34 days. Additional gastrointestinal symptoms were frequent (Table 2).

Among the 139 households interviewed, we identified 147 persons with laboratory-confirmed giardiasis (cases) and 239 persons who had neither diarrhea nor positive stool samples for *Giardia* (controls). Seventy-three per cent (108/147) of cases reported drinking two or more glasses of municipal water per day, compared to 36 per cent (86/239) of controls (OR = 4.9 95% CI = 3.1–8.0). Eighty-eight per cent (130/147) of cases were age 20 years or older, compared with 52 per cent (124/239) of controls (OR = 7.1 95% CI = 3.9–13.3). Conditional logistic regression analysis, used to match cases and controls by household and to control for age and water consumption, indicated that drinking two or more glasses of unboiled municipal water per day and being age 20 years or older were independently associated with giardiasis [OR (water) = 9.2 95% CI = 4.2–19.9; OR (age) = 3.3 95% CI = 1.7–6.2].

TABLE 1—Attack Rates by Residential Water Source, Laboratory-confirmed Cases of Giardiasis, Pittsfield, Massachusetts, November 1, 1985 to January 31, 1986

Water Source	Population	No. Cases	Attack Rate (per 1000)
Reservoir A	9405	68	7.2
Reservoir B	2309	14	6.1
Reservoir C	4200	126	30.0
Mixed (A, B, and C)	34351	427	12.4
TOTAL	50265	635	12.6
Residential water from reservoir C	**Population**	**No. Cases**	**Attack Rate (per 1000)**
Yes	38551	553	14.3
No	11714	82	7.0
TOTAL	50265	635	12.6

TABLE 2—Frequency of Symptoms, Laboratory-confirmed Cases of Giardiasis, Case-Household and Case-Telephone Surveys, Pittsfield, Massachusetts, November–December 1985

Symptom	Persons with Symptom (%)
Diarrhea (any duration)	236 (98)
(≥ 5 days)	190 (79)
Flatulence	214 (89)
Fatigue	207 (86)
Abdominal cramps	204 (85)
Loss of appetite	197 (82)
Bloating	180 (75)
Nausea	178 (74)
Weight loss	165 (69)
Vomiting	87 (36)
Fever (undocumented)	37 (15)
Bloody diarrhea	7 (3)
(N=240)	

Among 100 case-patients interviewed concerning the number of glasses of unboiled municipal water consumed at home or away from home, 74 reported that all or most of their water consumption occurred at home. They reported drinking a mean of 3.2 glasses per day at home, and 0.9 glasses per day away from home.

Community Telephone Survey

Of the 220 households selected, 200 were contacted; we obtained information on all 527 persons living in these households. Fourteen persons (2.6 per cent) had positive stool samples for *Giardia* since November 1 (confirmed cases); all of these persons had had diarrhea for ≥ 5 days before receiving treatment. Twenty-six persons (5 per cent) had diarrhea of undetermined etiology with ≥ 5 days duration (suspect cases). Projections from this survey indicated that between November 1, 1985 and January 15, 1986, 1,335 people (95% CI = 598–2072) had confirmed giardiasis and 2,480 additional persons (95% CI = 1426–3534) were suspect cases. The onset date of illness in suspect cases resembled that of the confirmed cases, suggesting that many of these suspect cases could have been outbreak-associated. Relatively few cases were reported with onset in January, which was also consistent with reports from laboratory-confirmed cases.

Of the 200 households interviewed, 189 (95 per cent) reported continuous compliance with a boil-water order that had been issued on December 12; 78 (39 per cent) were boiling municipal water, and 111 (56 per cent) were either using commercial bottled water or were obtaining water from local springs or wells. All respondents indicated awareness of the outbreak and the boil-water order.

Environmental Investigation

Daily records of free residual chlorine levels in water entering the distribution system immediately distal to the chlorination point indicated that chlorine levels in water from reservoir C were between 0 and 0.5 mg/l during the entire month of November due to a malfunction in the chlorinating machinery which was not successfully repaired until November 30. During December, chlorine levels in the distribution system water from reservoir C averaged 2 mg/l with approximately 15 minutes minimum contact time before water reached the first households. Chlorine levels in water entering the distribution system from reservoirs A and B immediately distal to the chlorination point during both months averaged 3 mg/l and 2 mg/l, respectively, with 15-minute minimum contact times. Water temperature in all three reservoirs was approximately 40°F, measured turbidity levels were within acceptable limits, and pH ranged from 7.0 to 7.4.

During October 1985, all bacterial cultures of water samples from various points in the distribution system contained levels of coliform bacteria below the acceptable limit of 4 colony forming units (CFU)/100 ml; no bacteria were detectable in 71 of 80 samples. However, on November 19, five days after the episode of turbid water (observed but not measured), five of 17 samples had > 5 CFU/100 ml. All of these five samples were taken from areas of the city that were at least partially supplied by water from reservoir C. Sampling was performed daily for the next seven days; after two days, all samples were negative for coliform bacteria except for a single site located in the region served exclusively by reservoir C, which continued yielding elevated coliform counts (8–41 CFU per 100 ml) until December 1, when the defective chlorinator was repaired.

Microscopic examination of water samples revealed that chlorinated water from reservoir C obtained immediately distal to the chlorination point contained 80 *Giardia* cysts/100 gallons; untreated water obtained directly from reservoir C contained 28 *Giardia* cysts/100 gallons. The samples obtained on December 16 directly from untreated water in reservoirs A and B contained seven cysts and nine cysts/100 gallons, respectively. Subsequent water samples taken from distal points in the distribution system in December and January yielded no *Giardia* cysts. *G. lamblia* cysts and trophozoites were detected in the laboratory animals inoculated with the extract from untreated reservoir C water; animals receiving portions of water samples obtained from reservoirs A and B were negative. Morphological studies suggested that the trophozoites obtained from reservoir C did not resemble those of beaver origin, but instead more resembled trophozoites found in humans. *Giardia* cysts that were isolated from the outbreak-related human fecal samples and inoculated in beavers and muskrats produced infection in both types of animals and also resembled *Giardia* typically of human origin.

The original source of contamination for reservoir C was not identified. Inspectors found no evidence of sewage contamination in any of the water mains or in any of the watershed areas of the three reservoirs. However, they encountered signs of human activity (graffiti and empty beverage containers) near the shoreline of reservoir C in officially restricted areas; they also noted many signs of recent beaver activity (fresh decorticated wood cuts) near reservoir C, and near a small pond that ultimately drained into reservoir B, but no evidence of beavers near reservoir A. Nine beavers were found during the December 1985 survey of the three watershed areas; one of three beavers found near reservoir C yielded stool samples positive for *Giardia*, compared to none of six beavers found in the watershed area of reservoir B. All of seven muskrats obtained during summer 1986 from watershed areas of all three reservoirs were infected with *Giardia*. Thus, the water and animal studies suggested that beavers and muskrats in the area contributed to contamination of the water supply and may have originally been infected from a human source, but they did not determine whether the reservoir water had also been directly contaminated by human sewage.

Control measures for the outbreak included the following:

- A boil-water order was issued on December 12, 1985. Pittsfield residents were asked to either boil municipal water or use alternative sources of drinking water.
- Reservoir C water was removed from the municipal water supply on December 21, 1985.
- Water in storage tanks and in the distribution system was hyperchlorinated and flushed in order to kill any remaining *Giardia* cysts that may have settled in the water mains. On December 21, free residual chlorine levels were increased to 3 mg/l, and minimum contact times with chlorine were increased to one hour. The entire distribution system was then flushed over a nine-day period.
- The boil-water order was removed after the following conditions were met: a) laboratory reports showed no evidence of significant increase in new illness after two incubation periods (four weeks) following completion of the hyperchlorination and flushing; b) results of the second community survey over the same two incubation periods were consistent with the data from confirmed cases, showing no evidence of continuing infection; c) adequate chlorination and contact times were maintained; d) water

sampling during January in the distribution system revealed no *Giardia* cysts.

- Continued weekly reporting of laboratory-confirmed cases of giardiasis was required for at least one month after removing the boil-water order.

The boil-water order was rescinded on January 24, 1986, six weeks after it was issued. As of April 1, 1986, only one case of giardiasis had been reported with onset of symptoms after late January.

Discussion

It is difficult to maintain appropriate concentrations of chlorine that prevent waterborne giardiasis; thus, communities should not rely upon chlorination alone to protect public water supplies. Proposed additions or alterations to municipal water supplies which lack filtration should be thoroughly evaluated to ensure that contamination levels do not exceed the capacity of the chlorination system. Untreated water should be examined for the presence of fecal coliforms, turbidity and, if possible, *Giardia* cysts. This outbreak was facilitated by a malfunction in the chlorinating machinery which left very low levels of chlorine in water from reservoir C, but even if chlorine levels had been maintained at 2 mg/l for 15 minutes as intended, viable *Giardia* cysts might still have been present; water at 40°F and pH 7.0 probably requires more than 30 minutes of contact with 2 mg/l of chlorine to adequately kill *Gardia* cysts.[9]

The dramatically increased incidence of illness noted during the last few days of November suggests that a relatively high dose of *Giardia* cysts was present in drinking water during a short period of time. Assuming a mean incubation period of two weeks, as is commonly described, the time course of infection implicates the episode of turbid water on November 14, 1985 as being potentially responsible for the increased number of cases. *Giardia* cysts that had settled to the bottom of water mains could have been resuspended by the increased turbulence in water flow. The result could have been a bolus of higher concentrations of *Giardia* cysts causing more infections. Additionally, the increased turbidity probably reduced the effect of chlorine which was already at inadequate levels. The increased concentrations of bacteria in water samples during the week following the episode of turbid water could have occurred as a result of inadequate chlorination.

The validity of calculating attack rates by place of residence to implicate a specific water source depends upon the assumption that most water consumption occurs at home; our survey supports this assumption. John Snow, the famous British epidemiologist, used this technique effectively to implicate the Southwark and Vauxhall Company as the source of contaminated water in his classic cholera investigations of 1853.[10]

This is the largest reported outbreak to date of laboratory-confirmed cases of waterborne giardiasis (703 cases). Previous investigations of waterborne giardiasis outbreaks have described a larger number of possible cases and community-wide attack rates of clinical illness ranging from 3.8 per cent to 10.6 per cent.[11–15] It is likely that those who obtained a laboratory diagnosis of their infection in Pittsfield represented only a portion of the infected population: the survey indicates 1.9 additional symptomatic suspect cases for every one laboratory-confirmed case. Additional persons were likely to have had asymptomatic infection. Estimates of numbers of infected persons in outbreaks depend upon the sensitivity and specificity of the case definition and on the accuracy and validity of telephone surveys.

Community health officials were encouraged by the high degree of reported compliance with their recommendations to avoid drinking unboiled municipal water. However, few people actually boiled tap water; most people were using alternate sources of drinking water although all were aware of the boil-water order.

It is ironic that this outbreak occurred as a result of the attempt to install a filtration system that would probably have prevented the outbreak. Many small communities lack filtered water supplies; they are costly and require technical expertise to maintain. In Massachusetts, among 124 surface water supplies, 76 had either no filtration system or partial filtration systems in 1985 (personal communication, John Higgins, Massachusetts Department of Environmental Quality Engineering). Giardiasis outbreaks may become even more frequent in the future, as increasing population pressure on watershed areas increase the risk of *Giardia* contamination for many communities that depend on unfiltered surface water supplies.

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