First Reported Outbreak in the United States of Cryptosporidiosis Associated with a Recreational Lake

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In the summer of 1994, an outbreak of cryptosporidiosis occurred among visitors to a state park in New Jersey. We enrolled 185 persons in a cohort study, 38 (20.5%) of whom had laboratory-confirmed cryptosporidiosis or gastrointestinal illness that met our clinical case definition. Having any exposure to lake water (e.g., swimming) was strongly associated with illness (P < .001). The outbreak lasted 4 weeks and affected an estimated 2,070 persons. The most likely sources of the outbreak were contaminated runoff of rainwater and infected bathers. This outbreak of cryptosporidiosis is the first reported to be associated with recreational exposure to lake water. Our investigation shows that even a large and ongoing outbreak may not be detected for several weeks. Health professionals and persons at high risk for severe cryptosporidiosis should be aware that recreational water can be a source of cryptosporidium infection.

The protozoan parasite Cryptosporidium parvum causes gastrointestinal illness and is transmitted by ingestion of oocysts excreted in the feces of infected humans or animals [1]. Outbreaks of cryptosporidiosis associated with exposure to drinking water [2–8], as well as water from swimming pools and water parks [4, 5, 9–17], have been reported previously. We report here the results of our investigation of the first documented outbreak of cryptosporidiosis in the United States associated with recreational use of lake water.

On 9 August 1994, the New Jersey State Department of Health became aware of gastrointestinal illness among persons who had swum in a small, shallow lake in a state park during late July or early August (figure 1). The first three stool specimens examined were positive for Cryptosporidium oocysts and negative for bacterial pathogens. On 12 August, the lake was closed.

Methods

Epidemiological Investigation

Initial investigation. In response to a press release, several hundred persons called the state or a local health department to report having had gastrointestinal illness after visiting the park. We asked these persons and their household members about the timing of their visit, contact with lake water, food and water consumption at the park, and gastrointestinal illness after their visit. In addition, we interviewed the lifeguards who had worked at the lake. Ill persons were asked to submit a stool specimen to the state health department.

Selection of study period and study cohort. Laboratory and preliminary interview data suggested that the first cases of cryptosporidiosis were in persons who had visited the park on or after 15 July. Therefore, 15 July through 12 August (the day the lake closed) was chosen as the study period.

From a list of 426 persons who had a single visit to the park, we randomly selected 228 persons for a cohort study, 43 of whom were excluded for various reasons (figure 2). We asked the 185 persons enrolled in the study about their contact with lake water, food and water consumption at the park, gastrointestinal illness after their visit, and potentially relevant exposures (e.g., contact with diaper-aged children) during the 2-week period before onset of illness (if ill) or during the 2-week period before their visit to the park (if well). For 81 (43.8%) of the 185 persons, we talked with a proxy, usually a parent (n = 52) or a spouse (n = 29). Approximately 60 ill and well persons were asked to submit a stool specimen.

Case definitions. A case-patient was defined as a person who visited the park once during the study period and either (1) developed gastrointestinal symptoms 2–14 days later and had a stool specimen that tested positive for Cryptosporidium (i.e., a confirmed case) or (2) developed diarrheal illness (≥3 loose or watery stools in a 24-hour period) 2–14 days later that lasted for ≥2 days (i.e., a probable case).

We also interviewed the persons who had visited the park multiple times during the study period and those persons who had laboratory-confirmed cryptosporidiosis but were not enrolled in the cohort study (figure 2). For persons who had visited the park multiple times, a case-patient was defined as
someone who had diarrheal illness that began 2–14 days after any visit and lasted for ≥2 days.

**Clinical Laboratory Investigation**

Stool specimens were transported in Cary-Blair medium and cultured for *Salmonella* and *Shigella* species by the state health department with use of standard techniques. Specimens fixed in 10% formalin and stained with the Kinyoun carbol-fuchsin modified acid-fast procedure [18] were examined for *Cryptosporidium* oocysts by both the state health department and the Centers for Disease Control and Prevention (CDC; reference laboratory). If the two laboratories had discordant results, the specimens were examined by the CDC for *Cryptosporidium* and *Giardia lamblia* with direct immunofluorescence (Meridian Diagnostics, Cincinnati, OH). Eleven specimens (fresh stool, stored at 4°C) from ill persons who had had diarrhea for at most several days were examined by the CDC by direct electron microscopy for viral particles (negative-staining technique [19]).

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**Figure 1.** Map of the lake, park facilities, and sites where the environmental investigation was conducted. The lake has an area of 26 acres (105,000 m²) and is, on average, 4 feet (1.2 m) deep. The swimming beach has a 42,160-square-foot (3,917 m²) swimming area.

**Figure 2.** Flow diagram of the selection of the study population, study cohort, and laboratory-confirmed case-patients. *A single park visit denotes having stayed at the park for ≤24 hours (e.g., for a picnic). Five persons who had moved overseas were excluded. Of these 228 persons, 34 (14.9%) had also been among the 588 persons who were interviewed by the health departments during the initial investigation. Representing 119 households. Had not been to the park during the study period (n = 6) or already had gastrointestinal symptoms when they went to the park (n = 2). Two of the 38 persons did not have gastrointestinal symptoms. Onset of diarrheal illness 2–14 days after visiting the park. Includes persons who had gastrointestinal illness 2–14 days after visiting the park that did not meet the case definition for diarrheal illness (n = 10) or had gastrointestinal illness with an incubation period <2 days (n = 1) or >14 days (n = 5). Had ≥3 loose or watery stools in a 24-hour period for ≥2 days.
Environmental Investigation

On 17 August, paired water samples from three lake sites (figure 1) and from a water fountain were each obtained by the filtering of 100 gallons of water through a 1-μm cartridge filter. The New Jersey American Water Company (NJAWC; Linwood, NJ) and the CDC each tested a set of the samples by indirect immunofluorescence for the presence of Cryptosporidium and Giardia [20–22]. On 21 September, additional water samples from the same three sites in the lake were obtained and tested by the NJAWC. From 7 August through 25 August, six water samples were obtained from the lake for routine microbiological analysis for total and fecal coliforms and for culturing for Shigella species. The park and surrounding area were inspected for possible sources of fecal contamination of the lake. On 22 August, to test for a leakage, fluorescein dye was flushed into the septic-tank system close to the beach area (figure 1); during the next 2 weeks, a total of nine water samples were obtained from the lake and tested photometrically for the presence of the fluorescein dye (detection limit, 15 μg/L).

Statistical Analysis

We used the χ² test to compare observed with expected proportions; computed 95% confidence intervals (CIs) for relative risks (RRs) by the Taylor series approximation; and computed two-tailed P values by using the χ² test or, when appropriate, Fisher’s exact test (if the latter was used, no CIs are given). We used Wilcoxon’s two-sample test to compare the ranked distributions of ordinal variables (e.g., duration of water contact). When we used the χ² test for linear trend (extended Mantel-Haenszel procedure), we also computed the corresponding χ² for the contingency table (2-by-2) to check for a significant departure from a linear trend; if the χ² values did not differ significantly, we provide only the P value for the linear trend. We used Epi-Info 6 for all statistical analyses [23].

Results

Epidemiological Investigation

Initial investigation. Through the initial telephone contacts, the health departments obtained information about 588 persons. Of the 429 persons who reported gastrointestinal illness, 385 (89.7%) had visited the park during the study period and 379 (88.3%) had self-defined diarrheal illness (figure 3). Among the 379 persons, 42 (11.1%) had laboratory-confirmed cryptosporidiosis with symptoms that began during the period from 20 July through 17 August (figure 3).

Cohort study: characteristics of the cohort and clinical symptoms. The median age of the 185 persons in the cohort study was 33.5 years (range, 2–76 years), 63 (34.1%) were children, and 99 (53.5%) were female. We identified 38 case-patients (20.5%; four had laboratory-confirmed and 34 had probable cases of cryptosporidiosis). Their clinical illness was characterized by gastrointestinal symptoms, fever, and headache; the median incubation period was 6.0 days (table 1). The clinical symptoms of the 38 case-patients from the cohort study were comparable to those of the 38 persons from outside the cohort study who had laboratory-confirmed cryptosporidiosis (table 1).

Cohort study: exposure characteristics and risk factors for illness. The attack rate (AR) for park-associated illness was 20.5% (38 of 185) among persons who had visited the park once during the study period (i.e., persons with a single visit) and 61.1% (11 of 18) among those who had visited more than once (i.e., persons with multiple visits; not in cohort study). Children with single visits and persons of all ages with multiple visits were more likely to have had contact with lake water (P < .001 and P = .03, respectively). Among persons with single visits, exposure to lake water was strongly associated with diarrheal illness (P < .001; table 2). The ARs among groups of exposed persons were relatively stable (on average, 64.1%) during the first 3 weeks of the outbreak period but were considerably lower in the fourth week (on average, 17.9%; P < .001). No common source other than lake water (e.g., food from the concession stand) was implicated by the analysis. The AR for diarrheal illness among children exposed to lake water was threefold higher than that among adults (P < .001; table 2). However, the difference in ARs between children and adults was no longer significant when controlled for type of exposure (e.g., facial or oral contact) or for duration of contact to lake water (table 2). Children tended to have more intense contact with lake water (e.g., were more likely to swallow water; P = .006) and had a longer median duration of contact with lake water (60.0 minutes vs. 15.0 minutes for adults; P < .001). Both intensity and duration of water contact were positively associated with illness (linear trends, P < .001) (table 2).

Estimated magnitude of the outbreak. During the study period, an estimated 3,491 persons had overnight stays at the park.
Table 1. Comparison of clinical characteristics of case-patients from the cohort study and laboratory-confirmed case-patients outside the cohort study.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>From cohort study</th>
<th>From outside cohort study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 38)</td>
<td>(Laboratory-confirmed; n = 38)¹</td>
</tr>
<tr>
<td>Symptom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diarrhea¹</td>
<td>38/38 (100)²</td>
<td>37/38 (97.4)</td>
</tr>
<tr>
<td>Median maximum number of diarrheal stools in a 24-h period (range)</td>
<td>5.5 (3–24)</td>
<td>6.0 (2–20)</td>
</tr>
<tr>
<td>Abdominal cramps</td>
<td>35/37 (94.5)</td>
<td>37/37 (100)</td>
</tr>
<tr>
<td>Flatulence</td>
<td>28/34 (82.4)</td>
<td>29/34 (85.3)</td>
</tr>
<tr>
<td>Nausea</td>
<td>28/37 (75.7)</td>
<td>33/35 (94.3)</td>
</tr>
<tr>
<td>Fever (self-defined)</td>
<td>23/34 (67.6)</td>
<td>25/35 (71.4)</td>
</tr>
<tr>
<td>Temperature of 99°F to ≤101°F</td>
<td>10/17 (58.8)</td>
<td>8/16 (50.0)</td>
</tr>
<tr>
<td>Temperature of &gt;101°F</td>
<td>6/17 (35.3)</td>
<td>7/16 (43.8)</td>
</tr>
<tr>
<td>Headache</td>
<td>22/35 (62.9)</td>
<td>28/31 (90.3)</td>
</tr>
<tr>
<td>Weight loss</td>
<td>17/35 (46.4)</td>
<td>23/32 (78.1)</td>
</tr>
<tr>
<td>Median loss, in kg (range)</td>
<td>2.0 (0.5–5.4)</td>
<td>1.8 (0.9–6.8)</td>
</tr>
<tr>
<td>Mucus in stool</td>
<td>13/27 (48.1)</td>
<td>13/28 (46.4)</td>
</tr>
<tr>
<td>Myalgia</td>
<td>14/35 (40.0)</td>
<td>18/31 (58.1)</td>
</tr>
<tr>
<td>Sore throat</td>
<td>13/34 (38.2)</td>
<td>8/35 (22.9)</td>
</tr>
<tr>
<td>Vomiting</td>
<td>14/37 (37.8)</td>
<td>25/38 (65.8)</td>
</tr>
<tr>
<td>Arthralgia</td>
<td>12/34 (35.3)</td>
<td>12/29 (41.4)</td>
</tr>
<tr>
<td>Epidemiological characteristic and severity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Median incubation period of gastrointestinal illness, in days (range)</td>
<td>6.0 (2–14)⁶</td>
<td>7.0 (1–17)</td>
</tr>
<tr>
<td>Median duration of gastrointestinal illness, in days (range)</td>
<td>11.0 (2–44)</td>
<td>10.5 (1–42)</td>
</tr>
<tr>
<td>Median duration of diarrhea, in days (range)</td>
<td>7.0 (2–44)</td>
<td>10.5 (1–42)</td>
</tr>
<tr>
<td>Unable to work or play</td>
<td>25/38 (65.8)</td>
<td>31/38 (81.6)</td>
</tr>
<tr>
<td>Median number of days unable to work or play (range)</td>
<td>5.0 (1–29)</td>
<td>7.0 (1–14)</td>
</tr>
<tr>
<td>Visited physician</td>
<td>9/38 (23.7)</td>
<td>13/38 (34.2)</td>
</tr>
<tr>
<td>Hospitalized</td>
<td>1/38 (2.6)</td>
<td>1/38 (2.6)</td>
</tr>
</tbody>
</table>

NOTE. Persons who did not remember if they had a particular symptom were excluded from the analysis for that variable. Clinical symptoms among laboratory-confirmed (n = 4) and probable (n = 34) case-patients within the cohort study were comparable, except for a higher rate of weight loss among confirmed case-patients (P = .045). The P values < .05 (comparing case-patients from the cohort study with persons outside the cohort study who had laboratory-confirmed cryptosporidiosis) were P = .009 (headache), P = .012 (weight loss), P = .015 (vomiting), P = .028 (nausea), and P = .012 (incubation period).

¹ Persons who had submitted a stool specimen after calling the state or a local health department in New Jersey; 25 (65.8%) of the 38 persons had visited the park more than once. Excludes two persons who had laboratory-confirmed cryptosporidiosis but did not have any gastrointestinal symptoms, as well as one person whose stool specimen was also positive for Giardia lamblia.

² By definition, probable case-patients had to have diarrhea.

³ Loose or watery stools (≥3 in a 24-hour period) for ≥2 days.

⁴ By definition, the incubation period for case-patients from the cohort study could not be outside the range of 2–14 days.
Table 2. Cohort study: age-stratified attack rates for diarrheal illness and relative risks, by type of lake-water exposure and duration of contact (n = 185).

<table>
<thead>
<tr>
<th>Exposure</th>
<th>All ages (n = 185)</th>
<th>Children¹ (n = 63)</th>
<th>Adults (n = 122)</th>
<th>RR (95% CI*)</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No exposure to lake water</td>
<td>3/90 (3.3)</td>
<td>0/9</td>
<td>3/81 (3.7)</td>
<td>Referent group</td>
<td>Referent group</td>
</tr>
<tr>
<td>Any exposure to lake water</td>
<td>35/95 (36.8)</td>
<td>28/54 (51.9)</td>
<td>7/41 (17.1)</td>
<td>11.05¹ (3.52–34.67); 3.04 (1.48–6.25);</td>
<td>P &lt; .001</td>
</tr>
<tr>
<td>Type of exposure</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No facial contact</td>
<td>0/18</td>
<td>0/6</td>
<td>0/12</td>
<td>Undefined</td>
<td>Undefined</td>
</tr>
<tr>
<td>Facial contact¹</td>
<td>4/13 (30.8)</td>
<td>3/7 (42.9)</td>
<td>1/6 (16.7)</td>
<td>9.23; P = .005</td>
<td>2.57; P = .56</td>
</tr>
<tr>
<td>Oral contact²</td>
<td>25/46 (54.3)</td>
<td>22/35 (62.9)</td>
<td>3/11 (27.3)</td>
<td>16.30 (5.20–51.17); 2.30; P = .08</td>
<td></td>
</tr>
<tr>
<td>Duration of contact³</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1–30 min</td>
<td>8/43 (18.6)</td>
<td>4/14 (28.6)</td>
<td>4/29 (13.8)</td>
<td>5.58; P = .005</td>
<td>2.07; P = .40</td>
</tr>
<tr>
<td>&gt;30 min</td>
<td>25/39 (64.1)</td>
<td>22/33 (66.7)</td>
<td>3/6 (50.0)</td>
<td>19.23 (6.17–59.96); 1.33; P = .65</td>
<td></td>
</tr>
</tbody>
</table>

* Where appropriate, Fisher’s exact test was used to compute the P values and no CIs are given.

¹ Aged <18 years.

² The RR was 12.07 (95% CI, 3.86–37.80; P < .001) if the 10 persons with gastrointestinal illness that did not meet the case definition for diarrheal illness were excluded from the analysis; the RR was 10.42 (95% CI, 3.90–27.83; P < .001) if these 10 persons were classified as case-patients.

Analysis for linear trend (no exposure to lake water vs. exposure to lake water but no facial contact vs. facial contact but no oral contact vs. oral contact): P < .001.

³ Swimming with face not in water, or canoeing. Two persons (one child and one adult) who were not sure whether they also had facial contact with lake water were excluded from the analysis.

** Getting water in mouth or swallowing water.

Analysis for linear trend (no exposure to lake water vs. contact for 1–30 minutes vs. contact for >30 minutes): P < .001; 13 persons (7 children and 6 adults) who were not sure how long they had contact with lake water were excluded from the analysis.

Clinical Laboratory Investigation

Of 73 persons who submitted a total of 93 stool specimens that were tested for Cryptosporidium, 46 (63.0%) had positive specimens: 39 (70.9%) of the 55 persons who had called the health departments, all 3 lifeguards (100%), and 4 (26.7%) of the 15 persons (one specimen each) from the cohort study (6 case-patients and 5 well persons from the cohort study had negative stool specimens). Two (4.2%) of the 48 specimens (from 48 persons) tested for Giardia were positive, one of which was also positive for Cryptosporidium. All 48 stool specimens (from 42 persons) tested for Salmonella and Shigella species were negative, as were the 11 fresh stool specimens (from 11 persons) tested for viral agents of gastroenteritis; one specimen contained a few small round-structured viruses (27 nm in diameter) of unknown significance.

Environmental Investigation

The drinking-water and all three lake-water samples obtained on 17 August were negative for Cryptosporidium oocysts. However, two of the three lake-water samples obtained on 21 September were positive for Cryptosporidium (7.2 and 21 oocysts per liter, respectively). None of the seven samples were positive for Giardia cysts.

Lake-water samples obtained on 10 August and 12 August showed high levels of fecal coliforms in the bathing area and in the adjacent canoe-docking area (500 and >1,600 fecal coliforms per 100 mL, respectively); regulations for bathing beaches in New Jersey require fecal coliform levels to be ≤200 per 100 mL [24]. On 17 and 25 August, after the lake was closed, the fecal coliform levels were ≤50 per 100 mL.

On 14 July, a backup of the septic-tank system occurred because of a pump failure. During this episode, sewage flooded a small area behind the concession stand, ~200 feet (61 m) from the beach, but reportedly no sewage entered the lake. However, the next day, 1.8 inches (4.6 cm) of rain fell within 6 hours and probably caused runoff from several areas around the lake. During most of the summer, little rain had fallen; consequently, turnover of water in the lake had been minimal.

The dye test of the septic-tank system did not show any leakage of sewage into the lake, and no other sources of potential fecal contamination (e.g., livestock farms) were found. However, anecdotal reports obtained during the telephone interviews indicated that small children wearing diapers had repeatedly been in the water during the summer, parents had rinsed soiled diapers in the swimming area, fecal accidents had occurred in the water several times before and during the outbreak period, and persons had entered the lake while having diarrheal illness.
Discussion

We have described the first documented outbreak in the United States of cryptosporidiosis associated with recreational use of lake water and the largest reported outbreak in the United States of which we are aware of any waterborne disease associated with a recreational lake. Although we estimated that 2,070 persons became ill, we probably underestimated the size of the outbreak by excluding secondary case-patients and persons whose gastrointestinal illness did not meet the case definition.

The epidemiological, clinical, and laboratory data are all consistent with the conclusion that Cryptosporidium caused this outbreak. The epidemiological data strongly implicate lake water as the source of the outbreak, which ended when the lake was closed. The fact that the highest ARs were among persons who stayed in the water the longest or who had the most intensive contact with water indicates the presence of a dose-response relationship between exposure to lake water and illness. Although recall bias may have led to an overreporting of more intensive contact with lake water by case-patients, it is unlikely to account for the strong association between exposure to lake water and illness. The similarity of clinical symptoms and severity of illness for probable and laboratory-confirmed case-patients suggests that the illness in probable case-patients was also caused by Cryptosporidium. However, we cannot rule out the possibility that some case-patients were infected with other or additional enteropathogens for which we did not test.

We did not definitively determine how the lake became contaminated and why the outbreak lasted 6 weeks. We hypothesize that on 15 July a large number of oocysts were flushed into the lake by contaminated runoff of rainwater from the area that had been flooded by sewage from the septic-tank system. Although the number of viable oocysts should have decreased by at least 99% at the observed warm water temperatures in the month thereafter [25, 26], some viable oocysts most likely still would have been present at the end of this period [26]. Given the small size of the lake and swimming area, the low infective dose of Cryptosporidium for humans [27] (possibly as low as one oocyst [28]), and the potentially high concentration of oocysts in the stool of persons with cryptosporidiosis [29], fecal contamination by infected persons (e.g., diaper-aged children or older persons who entered the lake while infected with Cryptosporidium) could have caused or perpetuated this outbreak.

The fact that no oocysts were found in lake water obtained shortly after the lake was closed by no means rules out the lake as the source of the outbreak. The current technology for sampling and testing water for oocysts is insensitive [30–32]. The relatively lower ARs at the end of the outbreak period, the absence of detectable oocysts shortly after the end of the outbreak period, and the low infective dose suggest oocyst levels in the lake may have been below the threshold of detection for the test method. The low levels of oocysts found nearly 6 weeks after the lake was closed were in the range typically found in surface waters [33–35], which commonly are contaminated with feces from free-living animals (e.g., deer) that may be infected with C. parvum [1]. The fact that current methodologies for testing water samples for Cryptosporidium are insensitive and expensive and require lengthy processing [36] precludes their use as routine screening tests for recreational waters and necessitates reliance on data about the presence of bacterial indicator organisms (e.g., fecal coliforms).

Recent studies indicate that virtually all rivers and lakes in the United States are contaminated with Cryptosporidium [33–35]. Contamination of natural bodies of recreational water poses a particularly difficult public health problem because such waters, in contrast to drinking water and water in conventional swimming pools, are not treated (i.e., disinfected or filtered) to remove or kill oocysts. Therefore, Cryptosporidium, as well as some other microbial contaminants, may survive for weeks.

To minimize fecal contamination and reduce the risk for waterborne illness, swimming areas should not be located where they may be affected by surface runoff (e.g., from sewage effluent); adequate toilet, hand-washing, and diaper-changing facilities should be provided at recreational areas; and signs should be posted that warn against drinking lake water, as well as defecating and rinsing diapers in lakes. The public should be educated that children wearing soiled diapers and persons experiencing or convalescing from a diarrheal illness should not enter recreational waters [5].

This outbreak shows that Cryptosporidium poses more than just a theoretical risk to recreational waters and that even a large and ongoing outbreak may not be detected for several weeks, especially if stool is not routinely examined for the etiologic agent and no surveillance system for the disease is in place. Physicians should consider the diagnosis of cryptosporidiosis for persons with prolonged diarrheal illness and should explicitly request such testing; a recent laboratory survey found that only 5% of clinical laboratories routinely test stool specimens for Cryptosporidium [37]. Medical and public-health personnel and persons at high risk for severe cryptosporidiosis (e.g., patients with AIDS) should be aware that recreational water can be a source of cryptosporidium infection.

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