Outbreak of Cryptosporidiosis Associated With a Man-Made Chlorinated Lake—Tarrant County, Texas, 2008

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Abstract **In July 2008, clusters of laboratory-confirmed cryptosporidiosis cases and reports of gastrointestinal illness in persons who visited a lake were reported to Tarrant County Public Health. In response, epidemiologic, laboratory, and environmental health investigations were initiated. A matched case-control study determined that swallowing the lake water was associated with illness (adjusted odds ratio = 16.3; 95% confidence interval: 2.5–infinity). The environmental health investigation narrowed down the potential sources of contamination. Laboratory testing detected *Cryptosporidium hominis* in case-patient stool specimens and *Cryptosporidium* species in lake water. It was only through the joint effort that epidemiologic, laboratory, and environmental health investigators could determine that >1 human diarrheal fecal incidents in the lake likely led to contamination of the water. This same collaborative effort will be needed to develop and maintain an effective national Model Aquatic Health Code.**

Introduction

On July 8, 2008, Tarrant County Public Health (TCPH) was notified of an outbreak of gastrointestinal illness among attendees of a picnic at a lake that was a man-made chlorinated recreational water venue (RWV). On July 9, a second group of lake visitors reported similar illness. On July 10, a local clinician called TCPH to report a cluster of three patients with laboratory-confirmed *Cryptosporidium* infection; all had visited the lake. By July 11, five laboratory-confirmed cases of cryptosporidiosis were identified among lake visitors and five separate groups reported gastrointestinal symptoms after visiting the lake.

Cryptosporidiosis is caused by the protozoan parasite *Cryptosporidium* and is characterized by watery diarrhea typically lasting one to four weeks in immunocompetent individuals (Hunter et al., 2004). *Cryptosporidium* can be transmitted by the fecal-oral route through the ingestion of contaminated water. Water at RWVs can become contaminated by the parasite when infected persons with diarrhea swim, when contaminated animal feces are introduced either directly or through water run-off, and as a result of deficiencies in human waste sanitation systems.

Cryptosporidium has been associated with three-quarters of reported outbreaks of gastroenteritis associated with treated RWVs (e.g., pools and interactive fountains) in the U.S. (1999–2008) (Hlavsa et al., 2011). The parasite's extreme tolerance of chlorine allows it to survive for 3.5–10.6 days in treated RWVs where the free chlorine level is maintained at 1–3 parts per million (ppm) (Shields, Hill, Arrowood, & Beach, 2008) as recommended by the Centers for Disease Control and Prevention (CDC). A standard protocol has been developed to remediate contaminated treated RWVs through a process called hyperchlorination, whereby the free chlorine contact time of 15,300 mg-min/L is achieved (e.g., maintaining free chlorine level at 20 ppm for 765 minutes) at water pH ≤7.5 and temperature ≥25°C (Shields et al., 2008).

Because of the clusters of laboratory-confirmed cryptosporidiosis cases and reports of gastrointestinal symptoms anecdotally associated with visiting the lake on the same day, TCPH launched an investigation in collaboration with the Texas Department of State Health Services (DSHS) and CDC. The objectives of the investigation were to confirm the lake as the outbreak source, determine the magnitude of the outbreak, identify risk factors associated with infection, identify the source contamination of the lake, and develop and implement control measures.

Methods

Epidemiologic and Laboratory Investigation

Cases were initially identified by clinicians, by self-report, or by contacting lake visitors whose names were registered in the lake's visitor logbook for June 28, 2008—the date that the first five identified laboratory-confirmed case patients visited the lake. Additional potential cases were identified during case-patient interviews conducted using a short questionnaire, which examined risk factors for *Cryptosporidium* infection in the community at large.

As the investigation continued, additional potential cases were also identified through activation of the existing local public health laboratory notifiable disease systems and the increased self-reporting that resulted from a TCPH press conference. Attempts to identify cases through other methods, such as review of credit card records, were unsuccessful. A standardized questionnaire focusing on the lake was then developed to include questions about specific water and food exposures at the lake, visits to other RWVs, and other potential exposures, such as exposure to animals, restaurants, and grocery stores.

To further delineate risk factors and assist the environmental health investigation, the standardized questionnaire was used in a matched case-control study of a subset of cases. Confirmed cases were defined as persons whose stool tested positive for *Cryptosporidium* and who developed at least one gastrointestinal symptom after June 20, 2008, following a visit to the lake. Probable cases were defined as persons with diarrhea characterized by ≥3 watery stools per day lasting ≥3 days, 2–10 days after June 20, 2008, following a visit to the lake. Controls were defined as a household contact of a confirmed or probable case who went to the lake on the same day as the case patient but did not develop gastrointestinal illness. If multiple household contacts were eligible to be controls, the one closest in age to the case was selected.

Power analysis indicated that 47 matched pairs would be needed to detect an odds ratio (*OR*) of 4.0 with a power of 80% and alpha of .05. Analysis was performed using SAS 9.2 statistical software. Differences in categorical variables were compared using the Cochran-Mantel-Haenszel test. Differences in medians were examined using the two-sample median test. Matched univariable and multivariable analyses of data on risk factors for infection were performed. Not all predictors significant in univariable analysis could be included in the multivariable analysis because of collinearity or sparseness of data. The study protocol was institutionally reviewed and determined not to be human-subjects research, as it was part of a public health response.

In addition to *Cryptosporidium* testing, the first 22 people with diarrheal illness at the time of interview were asked to submit stool for testing for *Salmonella*, *Shigella*, *E. coli*, *Campylobacter*, *Yersinia enterocolitica*, and norovirus by the Texas DSHS. When available, stool specimens from case patients were sent to CDC for *Cryptosporidium* testing. Genotyping and subtyping of *Cryptosporidium* isolates were also performed (Xiao et al., 2009).

Environmental Health and Laboratory Investigation

The objectives of the environmental health investigation were to determine if evidence existed of *Cryptosporidium* contamination of the lake, identify the source of contamination, address any identified sources of contamination, and determine the feasibility of remediating the lake using a hyperchlorination protocol. Water from the wells supplying the lake and the concession stand were tested for fecal coliforms. Additional samples for *Cryptosporidium* testing were taken from the wells, the lake itself, and the backwash of the two sand filters used to filter recirculated lake water.

Approximately 120 L were filtered for the composite lake and well samples and assayed following the U.S. Environmental Protection Agency (U.S. EPA) Method 1623 (U.S. EPA, 2001). In addition to immunofluorescence assay microscopy, CDC tested each sample using a *Cryptosporidium* genus-specific real-time polymerase chain reaction (PCR) assay (Jothikumar, da Silva, Moura, Qvarnstrom, & Hill, 2008). Drinking water sources were inspected. The property was inspected for potential sources of lake contamination, including the septic system, the restroom facilities, and the stream that runs along the border of the lake. Prior to recommending a remediation protocol, multiple lake samples from numerous locations were tested for free chlorine concentration, pH, and temperature to identify areas of poor circulation.

Results

Epidemiologic and Laboratory Investigation

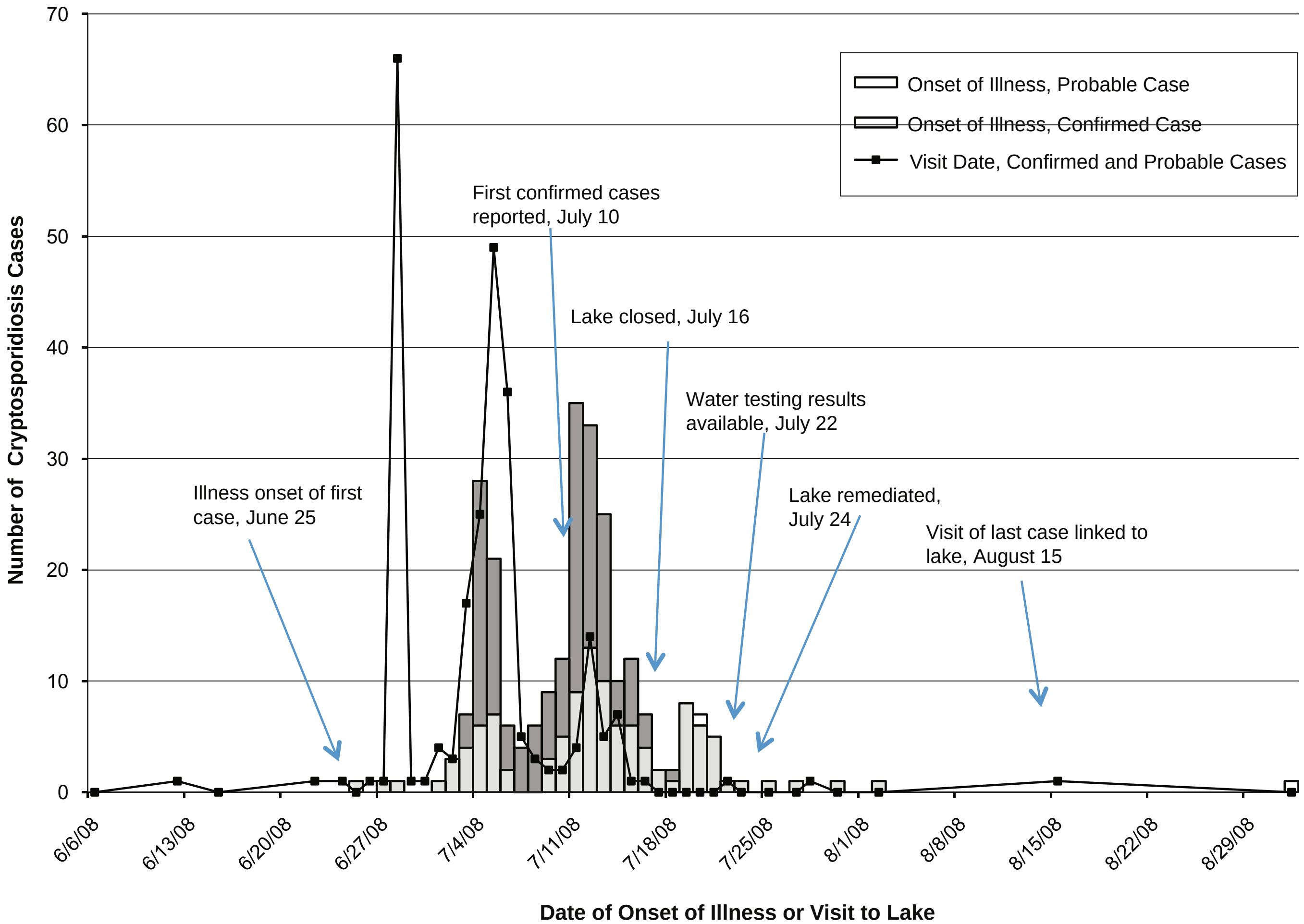
On July 14, a full-scale investigation was begun. On July 16, after the first laboratory-confirmed case with a different exposure date was identified, the lake was voluntarily closed. Investigators identified 112 confirmed and 142 probable case patients. The median age of case patients was 12 years (range: three months–61 years); 132 (52%) were male. The median incubation period was six days (range: 0–18 days). The epidemiologic curve (Figure 1) developed during the investigation demonstrates the three peaks of lake exposure, all of which occurred on weekends. The onset of symptoms then peaked 5–10 days after each exposure peak.

Fifty-six matched pairs were enrolled in the case-control study from among households that visited the lake. Demographic and exposure information collected from the cases and controls are summarized in Table 1. Males comprised 55.4% of cases compared with 28.6% of controls ($p = .009$). The median age of cases was 12.5 years compared with 32 years among controls ($p = .003$). Significant risk factors detected in univariable analysis (Table 2) included swallowing lake water (*OR* = 39.9), putting one's head under water (*OR* = 21.1), entering the lake (*OR* = 8.2), male sex (*OR* = 2.7), and younger age (*OR* = 0.95 for each year increasing age). Multivariable analysis (Table 2) revealed one significant risk factor: swallowing lake water (*OR* = 16.3; 95% confidence interval [*CI*]: 2.5–infinity). No differences between cases and controls were detected in regards to bringing one's own food to the lake, eating concession stand food, eating sno-cones made using water from one of the wells, or exposure to animals or pets.

Twenty-two potential case patients with diarrhea at the time of interview submitted stool specimens for additional testing. *Salmonella*, *Shigella*, *E. coli*, *Campylobacter*, *Y. enterocolitica*, and norovirus were not detected

FIGURE **1**

Probable and Confirmed Cases of Cryptosporidiosis Associated With a Lake—Tarrant County, Texas, 2008 (*N* = 253*)



*One case patient with laboratory-confirmed cryptosporidiosis could remember the date of visit to the lake but not the exact date of symptom onset. The person did report that the symptom onset was after June 20, 2008.

in any of the stool specimens. *Cryptosporidium hominis* was detected in 12 specimens. Ten isolates were of the IaA28R4 subtype and two were of the IaA15R3 subtype. The latter came from stool specimens from two case patients from one family who had visited the lake on July 11.

Environmental Health and Laboratory Investigation

The lake is a sandy bottom lake that reaches a depth of up to 10 ft., contains approximately two million gallons of water, and has an estimated turnover rate of 1.5 days (i.e., the crude estimated time for recirculation of the entire volume of lake water through the filtration system). On summer weekends approximately 2,000 people visit daily. The lake is not considered a pool under Texas code and is not regulated under that code. Four wells on the property feed the lake. A fifth well supplies disinfected water for the concession stand and other potable water needs. Chlorinated water from one well is fed through a circular manifold installed in the deepest area of the lake. Water drawn from the lake bottom is pumped through two rapid sand filters and returned without additional chlorination. The shoreline and bottom are irregular, potentially creating regions of poor circulation. Additional structures on the property include a concession stand; six toilets and a hand washing station that receive water from a separately chlorinated line originating from a well that also feeds the lake; and a septic system that integrates three septic tanks with a dispersion field located >100 ft. from the lake and wells.

The lake's concession stand had passed all health inspections during the 2008 swimming season. TCPH inspectors found no cross connections between the water sup-

TABLE **1**

Characteristics and Exposures Among Participants in the Matched Case-Control Study

General Characteristics	Cases (*n* 56)		Controls (*n* 56)		*p*-Value[a]
	#	%[b]	#	%[b]	
Male sex	31	55.4	16	28.6	.009
Age in years: median (range)	12.5	(0.3–61)	32	(0.3–63)	.003[c]
Race/ethnicity					
Caucasian	43	76.8	45	80.4	.61
Hispanic	12	21.4	10	17.9	
Other[d]	1	1.8	1	1.8	
Exposures					
Entered the water	56	100	50	89.3	.01
Put head under water	55	98.2	40	71.4	.0001
Swallowed lake water	49	89.1	21	38.2	<.0001
Brought own food to lake	53	94.6	53	94.6	?[e]
Ate concession stand food	13	23.2	9	16.1	.1
Ate concession stand sno-cone	6	10.7	5	8.9	?[e]
Contact with animals/pets	44	80	41	74.6	.31

[a]All *p*-values from Cochran-Mantel-Haenszel test and adjusted for matching except where noted.
[b]Occasionally data were missing so the percentage may be calculated using an $n < 56$.
[c]*p*-Value for two-sample median test.
[d]Other includes Asian and American Indian or Alaska Native.
[e]No *p*-value calculated as ≤1 discordant pair.

TABLE **2**

Univariable and Multivariable Predictors of Gastrointestinal Illness After Visit to the Lake

Variable	Univariable		Multivariable	
	OR[a]	95% *CI*[a]	*OR*[a]	95% *CI*[a]
Age in years (continuous)	0.95[b]	0.9–1.0[b]	0.97[c]	0.9–1.0[c]
Male sex	2.7	1.2–5.7	3.6	0.9–29.8
Entered the water	8.2	1.2–infinity	•••[d]	•••
Put head under water	21.1	3.6–infinity	4.8	0.4–infinity
Swallowed lake water	39.9	7.1–infinity	16.3	2.5–infinity
Ate concession stand food	5.0	0.6–42.8	•••	•••
Ate concession stand sno-cone	1.0	0–39	•••	•••
Contact with animals/pets	3.0	0.3–28.8	•••	•••

[a]Matched odds ratio. *CI* = confidence interval.
[b]*p*-value = .0006.
[c]*p*-value = .27.
[d]Variable not included in the multivariable model.

ply line serving the lake and the restrooms. Additional portable toilets were available on weekends. No evidence of septic system malfunction was found. No fecal coliforms were detected in the three wells that could be assessed. *Cryptosporidium* species were detected in the 120-L composite lake sample by microscopy (U.S. EPA Method 1623) and real-time PCR. *Cryptosporidium* was not detected in the composite well water sample. The parasite was also detected in one filter backwash sample by real-time PCR. Neither isolate could be speciated.

The free chlorine level (range: 0.0–0.6 ppm), pH (range: 7.0–8.0), and water temperature (range: 85°F–88°F [29.4°C–31.1°C]) were measured at multiple points in the lake and measurements were similar. All measurement points were recorded using GPS technology so that the same points could be monitored throughout the hyperchlorination process. The lake was hyperchlorinated to inactivate *Cryptosporidium* on July 24 by the owner under the supervision of TCPH environmental health officials. Hourly samples were collected from five representative locations in the lake and from a port on the recirculation system. Free chlorine levels ≥20 ppm were achieved throughout the lake on July 24 at 10:15 p.m. and maintained for 13 hours. The chlorine level dropped to 8 ppm on July 27 and the lake was reopened. The hyperchlorination protocol required the addition of nearly 1,700 pounds of chlorine. Investigators identified only two cases of cryptosporidiosis associated with the lake after implementation of the hyperchlorination protocol.

Discussion

The report of a small cluster of cryptosporidiosis cases to TCPH by the proverbial "astute clinician" helped identify an outbreak that was linked to a man-made chlorinated lake. The epidemiologic investigation produced an epidemiologic curve that revealed repeated exposure to a contaminant at the lake and a 5–10 day delay between exposure to the lake and symptom onset, which is consistent with the incubation period of cryptosporidiosis. The case-control study determined that the key risk factor for infection was swallowing the lake water. The laboratory and environmental health investigation narrowed down the potential sources of contamination.

Laboratory testing detected *Cryptosporidium hominis*, a species that is predominantly transmitted anthroponotically, in stool specimens; *Cryptosporidium* species were also detected in the lake and the filter backwash. Together, the epidemiologic, laboratory, and environmental health investigations could eliminate all but two potential contamination sources (i.e., two covered, inaccessible wells and ≥1 human diarrheal fecal incidents in the water). As *C. hominis* was the outbreak's etiologic agent, the contamination of the lake could have been due to introduction of the parasite through ≥1 human diarrheal fecal incidents in the water.

This is the first reported recreational water illness (RWI) outbreak associated with a man-made chlorinated lake. The chlorine levels detected in this lake were too low to inactivate pathogens, particularly *Cryptosporidium*. It should be noted that the outbreak occurred in the context of a community-wide outbreak of cryptosporidiosis. For 2008, more than 3,000 cryptosporidiosis cases were reported in Texas (Yoder, Harral, & Beach, 2010). This was a greater than 14-fold increase from 2007. Over two-thirds of the case patients resided in Collin, Dallas, Denton, and Tarrant counties in the Dallas-Fort Worth metropolitan area.

The emergence of *Cryptosporidium* as one of the leading causes of outbreaks associated with treated RWVs and community-wide cryptosporidiosis outbreaks call for a vigorous national effort to educate the public about the critical role of swimmer hygiene (e.g., not swimming while ill with diarrhea) and not swallowing recreational water. Available data suggest that *C. hominis* might be more virulent than *C. parvum* and that the clinical presentation of *C. hominis* infection varies by subtype (Cama et al., 2008; Hunter et al., 2004). The IaA28R4 subtype of *C. hominis* identified in this outbreak has been identified in several other U.S. RWI outbreaks and is becoming the dominant *C. hominis* subtype in outbreaks and sporadic cases (Xiao et al., 2009; Xiao & Ryan, 2008).

Secondary/supplemental disinfection that can inactivate *Cryptosporidium* (e.g., ultraviolet light or ozone systems [Betancourt & Rose, 2004; Craik, Weldon, Finch, Bolton, & Belosevic, 2001; Rochelle, Upton, Montelone, & Woods, 2005]) and reduce risk of transmission of this extremely chlorine-tolerant parasite needs to be considered as part of standard operation of the nation's treated RWVs (Centers for Disease Control and Prevention, 2007). Of note, CDC does not recommend hyperchlorinating lakes and other natural bodies of water in response to cryptosporidiosis outbreaks.

Pool codes in the U.S. are reviewed and approved by individual state or local public health officials. Although the Virginia Graeme Baker Pool and Spa Safety Act of 2007 (15 U.S.C. §§ 8001 et seq.), which was designed to reduce the risk of entrapment, appointed the U.S. Consumer Product Safety Commission to regulate one limited aspect of pool and spa safety, no other federal agency is responsible for regulating other aspects of treated RWVs. As a result, pool codes can vary widely among jurisdictions and no uniform national standards govern the design, construction, operation, and maintenance of treated RWVs. This disparate approach to RWI prevention can lead to inefficiency and gaps in effective public health policy, as lessons learned from RWI outbreak investigations in one jurisdiction might have to be relearned in another. A national model pool code that captures the lessons learned by all jurisdictions and is based on the latest epidemiologic, laboratory, and environmental health data identifying RWI risk factors or the most effective RWI prevention and control measures is needed.

One such effort to create a model, the national Model Aquatic Health Code (MAHC) (www.cdc.gov/healthywater/swimming/pools/mahc/structure-content), is being sponsored by CDC and led by the New York State Department of Health and an all-stakeholder multidisciplinary steering committee. The MAHC will be a free, open-access, evidence-based model health code that aims to reduce illness and injury associated with treated RWVs. It will set a research agenda for aquatic health and safety, and like the Food and Drug Administration food code, will be updated regularly. The MAHC is a collaborative effort between public health officials and the aquatics sector.

Making the best available standards and practices available for voluntary adoption by state and local agencies, the MAHC should increase the efficiency of environmental health pool programs. This can be accomplished by pooling resources across jurisdictions to create one model code based on the latest science and sharing lessons learned and then making this resource available to state and local jurisdictions as they review and update their public health laws related to the prevention of swimming-associated illness and injury. Effective implementation of a unified approach to RWI prevention involving improved staff and patron hygiene, engineering enhancement, and regulatory improvement should reduce the risk of RWI in the future.

Our investigation had multiple limitations. Because this outbreak occurred in the context of community-wide outbreak and additional concurrent public health emergencies, resources were not available to interview all cases for the case-control study. Recall bias resulting from conducting interviews after weeks had elapsed since infection and the TCPH press conference might have influenced responses from case patients and controls. Two of the five wells could not be accessed for microbial testing, and the investigation was dependent on voluntary cooperation of the beach manager as the lake was not regulated as a pool or lake by Texas code.

Conclusion

Our investigation highlights the importance of close cooperation among epidemiology, laboratory, and environmental health colleagues in response to RWI outbreaks. While the epidemiologic investigation identified cases and risk factors associated with the outbreak and the laboratory investigation confirmed the etiologic agent, it was the environmental health investigation that narrowed down the possible explanations of how the water was contaminated. Only by combining results of the three components of this collaborative investigation could the team conclude that the lake was likely contaminated by ≥1 human diarrheal fecal incidents in the lake and make control recommendations.

Given the importance of the contribution of the environmental health perspective to RWI outbreak investigations, it is troubling that reports to CDC about RWI outbreaks often include laboratory and in-depth epidemiologic data but limited environmental health data. For example, reports to CDC on 89 (66.4%) of the 134 RWI outbreaks (2007–2008) presented either no or inadequate environmental health data. It is unclear whether this is because environmental health investigations are not conducted or because the environmental health data are not reported to CDC. The shortage of environmental health data from outbreak investigations represents a missed opportunity to better identify the factors that contribute to the contamination of recreational water and implement the most effective RWI prevention and control measures. As collaboration between epidemiology, laboratory, and environmental health are required for the successful completion of this and other outbreak investigations, their collaborative input will also be needed for the development and maintenance of an effective MAHC.

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