An Outbreak of *Vibrio cholerae* O1 Infections on Ebeye Island, Republic of the Marshall Islands, Associated with Use of an Adequately Chlorinated Water Source

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In December 2000, physicians in the Republic of the Marshall Islands reported the first known outbreak of *Vibrio cholerae* O1 infection (biotype El Tor, serotype Ogawa) from this country. In a matched case-control study on Ebeye Island, patients with cholera ($n = 53$) had greater odds than persons without cholera ($n = 104$) to have drunk adequately chlorinated water collected from a US military installation on neighboring Kwajalein Island and transported back to Ebeye (matched odds ratio [MOR], 8.0; $P = .01$). Transporting or storing drinking water in a water cooler with a spout and a tight-fitting lid was associated with reduced odds of illness (MOR, 0.24; $P < .01$), as was drinking bottled water (MOR, 0.08; $P < .01$), boiled water (MOR, 0.47; $P = .02$), or water flavored with powdered drink mixes (MOR, 0.18; $P < .01$). No cases of cholera were reported among Kwajalein residents. This outbreak highlights the critical importance of handling and storing drinking water safely, especially during outbreaks of gastrointestinal illness.

During early December 2000, physicians in the Republic of the Marshall Islands (RMI) reported a sudden increase in the number of acute, severely dehydrating diarrheal illnesses among adults on the island of Ebeye. Shortly thereafter, a similar increase in diarrheal illnesses was reported on Lae Island, in Lae Atoll, 100 miles away. Three of 5 stool specimens (2 from Ebeye and 1 from Lae) sent to regional reference laboratories yielded toxigenic *Vibrio cholerae* O1, biotype El Tor, serotype Ogawa, confirming a cholera outbreak. There had been no previous reports of *V. cholerae* O1 infections from the RMI, although the neighboring nation to the west, the Federated States of Micronesia (FSM), experienced a large *V. cholerae* O1 outbreak from April 2000 to December 2000 [1].

The RMI consists of 1225 islands in 29 atolls and is located 2000 miles southwest of Hawaii (figure 1). Ebeye Island, in Kwajalein Atoll, is the second-most populated island in the Republic, with 9345 persons on a land area of 0.12 square miles. Kwajalein Island, 4 miles south of Ebeye, is leased to the United States military and partly supports the economy of Ebeye through wages and lease payments made to the landowners. Ebeye is geographically divided into 3 admin-

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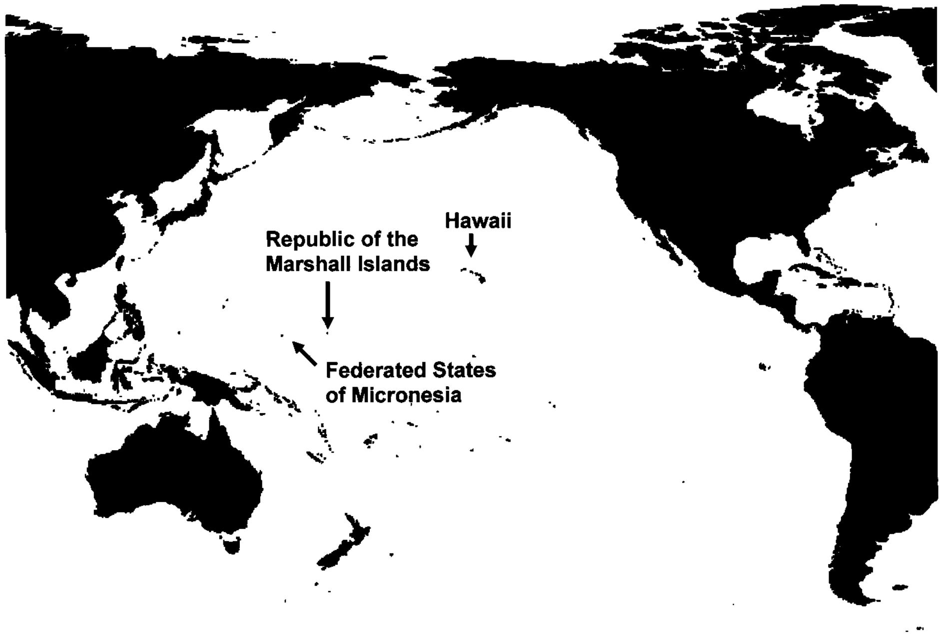

Figure 1. Geographic location of the Republic of the Marshall Islands

istrative zones. One 35-bed hospital provides all health services; capacity for bacterial culturing is lacking.

Households on Ebeye consist of extended families living in overcrowded and aging single-story multiroom structures. Dietary staples include rice, chicken, fish, imported canned meats, and other processed foods. There are no fresh water springs. Available water sources include chlorinated water from the US military facility on the neighboring island of Kwajalein (transported by individuals, often children, in containers via ferry from Kwajalein to Ebeye), municipal piped water on Ebeye, commercial bottled water, and rainwater. Water for the municipal system on Ebeye is generated via reverse osmosis of seawater supplemented by rainwater; the plant often malfunctioned prior to the outbreak, and coliform contamination was repeatedly documented in the distribution system. Bottled drinking water is available at local stores. Sanitation is poor.

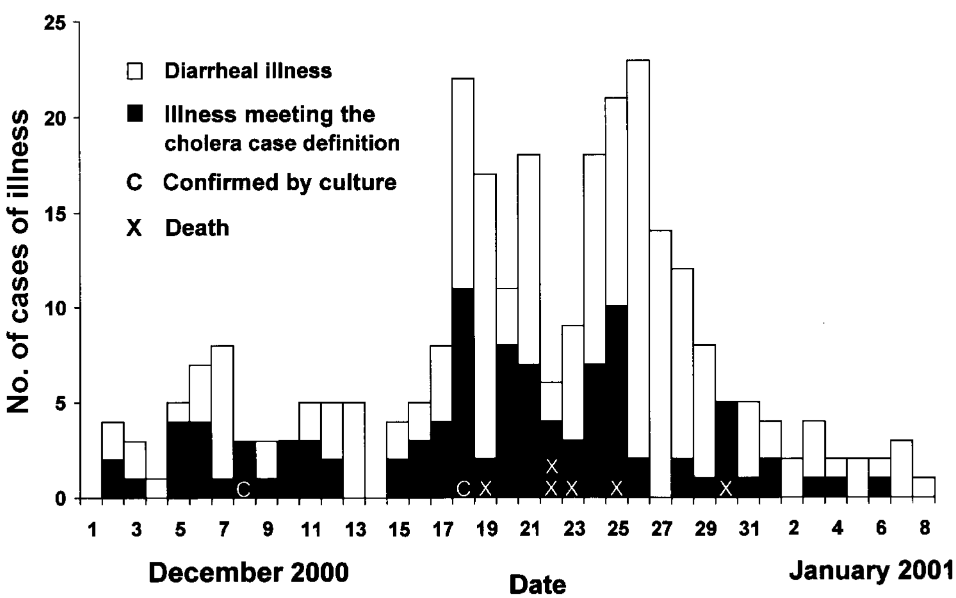

Figure 2. Cases of diarrheal illness reported to Ebeye Hospital, Ebeye Island, December 2000–January 2001 (n = 278)

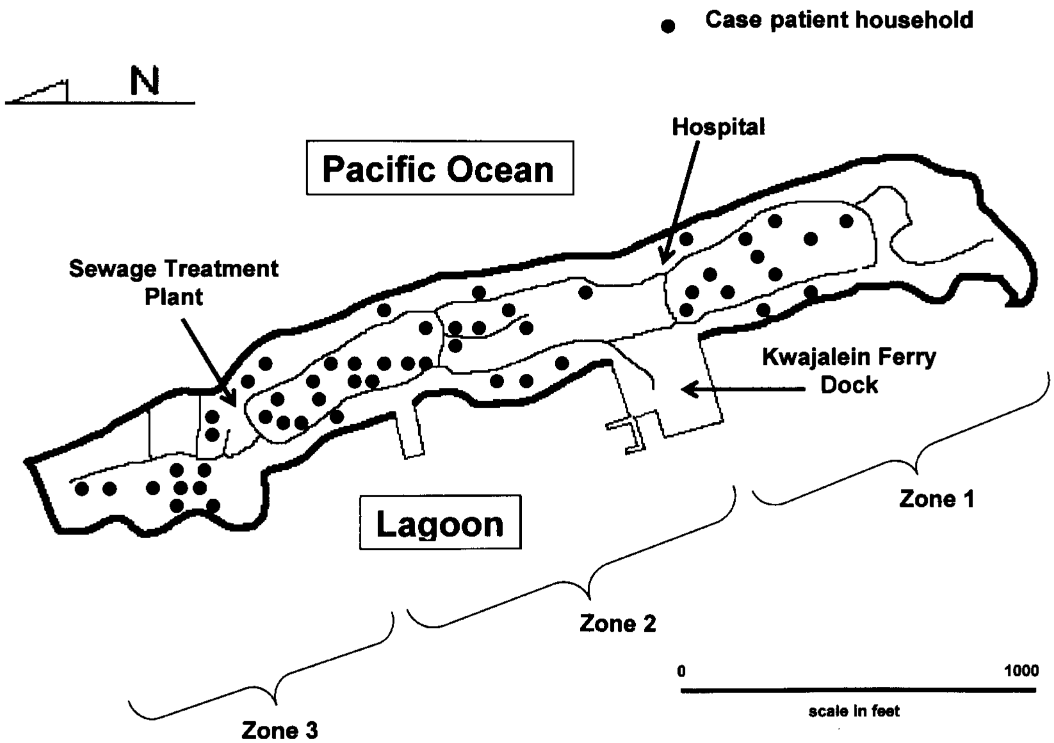

Figure 3. Area of residence of case patients on Ebeye Island

The sewage treatment plant had been nonoperational since 1996; raw sewage was discharged untreated into the Ebeye lagoon and often overflowed onto streets during storms.

METHODS

Surveillance and case-control study. Data were collected during an outbreak investigation and did not involve human experimentation. Ebeye Hospital maintains handwritten logs of all patient visits; these logs contain names, dates of visit, diagnoses, and disposition (e.g., admitted). We defined a case of cholera as being present in any patient >5 years old presenting to Ebeye Hospital with acute onset of watery or nonbloody diarrhea (defined as >3 loose stools per 24-h period). We calculated attack rates overall and by administrative zone using 1999 census data (the most recent data available).

We conducted a matched case-control study to identify risk factors for developing cholera. We identified case patients from among persons who presented to the Ebeye Hospital between 1 December 2000 and 6 January 2001 with illness that satisfied our case definition. We defined as "index cases" those cases present in persons whom we determined to be the first person in their household with cholera. We attempted to match each index case patient to 2 control subjects by age, sex, and neighborhood of residence using a randomized selection procedure. Potential control subjects were excluded if they had not resided on Ebeye during all 5 days before onset of diarrhea in the case patient to whom they were matched; if they or anyone in their household reported diarrhea in the month before the case patient's onset of diarrhea; if they had received a cholera vaccination (in response to the outbreak, ~40% of residents were vaccinated by 1 January 2001 with the CVD 103-HgR attenuated live oral cholera vaccine); or if they declined to provide the blood sample that was requested as part of the serologic investigation.

In addition to investigating risk factors for cholera, the data collection instrument included observational data related to socioeconomic status and probed how respondents received public health messages disseminated during the outbreak. The data collection instrument was translated from English to Marshallese and then translated back into English to ensure the translated questions matched their intent in English. Community health workers completed interviews in the respondents' homes.

Microbiologic and serologic investigation. Beginning on 7 January 2001, two rectal swab specimens were collected from each patient presenting to Ebeye Hospital with suspected cholera and were placed in Cary-Blair transport media. At the Ebeye Hospital laboratory, 1 swab was plated onto thiosulfate citrate bile sucrose agar, and colonies with an appearance that was

Table 1. Demographic and exposure data for case patients and control subjects and association with cholera illness during a *Vibrio cholerae* O1 outbreak on Ebeye Island, December 2000.

	n/N (%)[a]		Association with cholera illness			
			By clinical definition		By serologic definition	
Variable	Case patients	Control subjects	Matched OR (95% CI)	*P*	Matched OR (95% CI)	*P*
Primary water source						
Kwajalein military base	51/53 (96)	85/104 (82)	4.56 (1.08–39.99)	.02	3.19 (0.71–29.49)	.09
Ebeye municipal system	0/53 (0)	1/104 (1)	…	…	…	…
Bottled water	0/53 (0)	8/104 (8)	…	…	…	…
Rainwater	1/53 (2)	7/104 (7)	0.08 (0.00–0.69)	<.01	0.01 (0.00–1.00)	.03
Any use as a water source						
Kwajalein military base	52/53 (98)	88/104 (85)	8.00 (1.24–335.48)	.01	5.42 (0.76–236.70)	.06
Ebeye municipal system	2/53 (4)	1/104 (1)	1.00 (0.05–59.00)	.74	0.50 (0.01–39.25)	.56
Bottled water	7/53 (13)	42/104 (40)	0.08 (0.02–0.22)	<.01	0.10 (0.02–0.37)	<.01
Rainwater	5/53 (9)	18/103 (17)	0.17 (0.03–0.67)	<.01	0.07 (0.00–0.56)	<.01
Primary water transport container						
Bucket with lid	32/52 (62)	66/88 (75)	0.42 (0.17–1.03)	.03	0.48 (0.16–1.37)	.10
Narrow-mouthed jug with or without lid	32/52 (62)	57/88 (65)	0.72 (0.32–1.67)	.25	0.79 (0.28–2.34)	.40
Insulated water cooler[b]	14/52 (27)	33/88 (38)	0.33 (0.11–0.89)	.01	0.22 (0.04–0.88)	.01
Primary water storage container						
Bucket with lid	30/52 (58)	61/88 (69)	0.45 (0.18–1.06)	.03	0.46 (0.14–1.40)	.10
Narrow-mouthed jug with or without lid	35/52 (67)	55/88 (63)	0.76 (0.33–1.76)	.30	0.84 (0.27–2.69)	.46
Insulated water cooler[b]	20/52 (38)	50/88 (57)	0.26 (0.11–0.61)	<.01	0.22 (0.06–0.64)	<.01
Any use of container to transport or store water						
Bucket with lid	33/52 (63)	65/88 (74)	0.41 (0.16–1.00)	.02	0.41 (0.13–1.20)	.06
Narrow-mouthed jug with or without lid	37/52 (71)	61/88 (69)	0.76 (0.32–1.83)	.31	0.84 (0.27–2.69)	.46
Insulated water cooler[b]	21/52 (40)	52/88 (59)	0.24 (0.09–0.58)	<.01	0.18 (0.04–0.60)	<.01
Means of transferring water for storage or drinking						
Pouring	45/52 (88)	70/88 (80)	1.70 (0.62–5.37)	.19	1.82 (0.45–10.62)	.28
Scooping	23/52 (44)	45/88 (51)	0.42 (0.17–1.02)	.03	0.38 (0.10–1.34)	.08
Removal via spout in vessel	16/52 (31)	40/88 (45)	0.36 (0.14–0.83)	<.01	0.28 (0.07–0.80)	<.01
Drinking water treatment						
Boiling	20/49 (41)	46/101 (46)	0.47 (0.22–0.98)	.02	0.44 (0.17–1.12)	.05
Chlorination by user	3/51 (6)	0/101 (0)	…	…	…	…
Use of powdered drink mix	11/53 (21)	42/104 (40)	0.18 (0.08–0.37)	<.01	0.18 (0.06–0.44)	<.01
Food consumed within 5 days before onset of illness in case patient						
Produce						
Fruit (excluding breadfruit)	23/51 (45)	57/94 (61)	0.28 (0.13–0.60)	<.01	0.41 (0.16–1.00)	.03
Fermented breadfruit	8/52 (15)	10/104 (10)	0.44 (0.14–1.38)	.09	0.74 (0.20–2.99)	.41
Vegetables	15/51 (29)	65/102 (64)	0.14 (0.06–0.30)	<.01	0.11 (0.03–0.30)	<.01
Rice, cooked	53/53 (100)	104/104 (100)	…	…	…	…
Rice, at room temperature	30/53 (57)	48/104 (46)	0.71 (0.35–1.49)	.20	0.65 (0.28–1.60)	.20
Meat, fish, and poultry						
Eggs, fresh	31/52 (60)	90/103 (87)	0.14 (0.05–0.37)	<.01	0.15 (0.04–0.47)	<.01
Chicken, fresh or frozen	47/52 (90)	99/103 (96)	0.40 (0.08–1.86)	.40	0.50 (0.09–2.68)	.26
Beef, fresh	22/52 (42)	66/103 (64)	0.20 (0.08–0.44)	<.01	0.18 (0.06–0.48)	<.01
Pork, fresh	8/53 (15)	13/104 (13)	0.44 (0.14–1.38)	.09	0.25 (0.04–1.17)	.04
Canned meat and/or fish	48/53 (91)	102/104 (98)	0.20 (0.02–1.22)	.05	0.25 (0.00–4.80)	.26
Shellfish (lobster, crab, shrimp, or bivalves)	4/52 (8)	11/103 (11)	0.23 (0.05–0.84)	.01	0.50 (0.04–4.51)	.38
Pelagic fish	37/53 (70)	67/103 (65)	0.73 (0.35–1.56)	.23	0.61 (0.25–1.50)	.16
Salt fish	8/37 (22)	30/67 (45)	0.27 (0.09–0.75)	.01	0.23 (0.04–0.94)	.02
Raw fish	17/37 (46)	40/67 (60)	0.52 (0.19–1.36)	.10	0.71 (0.21–2.41)	.35

(continued)

Table 1. *(Continued.)*

Variable	n/N (%)[a] Case patients	Control subjects	Association with cholera illness: By clinical definition Matched OR (95% CI)	P	By serologic definition Matched OR (95% CI)	P
Lagoon fish	18/31 (58)	33/58 (57)	1.00 (0.30–3.56)	.61	4.21 (0.50–197.09)	.15
Ocean fish	7/31 (23)	19/56 (34)	0.45 (0.11–1.58)	.13	0.46 (0.07–2.41)	.23
Exposure to public health messages about cholera						
By radio show	34/53 (64)	81/104 (78)	0.31 (0.14–0.70)	<.01	0.34 (0.12–0.92)	.02
By pamphlet	23/53 (43)	38/104 (37)	0.51 (0.25–1.04)	.03	0.50 (0.20–1.27)	.08
By town meeting	21/53 (40)	37/104 (36)	0.58 (0.27–1.25)	.09	0.50 (0.18–1.42)	.11
Markers of socioeconomic status						
Owned a car	7/53 (13)	13/104 (13)	0.35 (0.11–1.02)	.03	0.23 (0.04–1.00)	.03
Owned a stove	52/53 (98)	100/103 (97)	1.82 (0.14–98.40)	.52	0.50 (0.01–39.25)	.56
Owned a freezer	37/53 (70)	78/104 (7 5)	0.50 (0.22–1.13)	.05	0.67 (0.22–2.13)	.29
Employed	16/53 (30)	25/104 (24)	0.59 (0.24–1.46)	.15	0.67 (0.22–2.13)	.29

[a] Data are no. of respondents answering in the affirmative/no. of respondents (%). Case patients and control subjects
[b] Insulated vessel with a screw-top lid and spout.

characteristic of *V. cholerae* were subcultured and tested by agglutination with polyvalent O1 and monovalent Inaba and Ogawa antisera [2]. The second swab was forwarded to the Centers for Disease Control and Prevention (CDC; Atlanta, GA) for confirmatory testing and determination of antibiotic susceptibilities for any isolated *V. cholerae* O1 by disc diffusion [3]. The initial 3 *V. cholerae* O1 isolates from Ebeye and Lae residents were forwarded to the CDC for laboratory confirmation and subtyping by PFGE. Isolates were processed using a rapid, 1-day standardized PFGE protocol with modifications [4]. The DNA embedded plugs were restricted with the restriction enzyme *Not*I. The PFGE gel was analyzed using BioNumerics, version 2.5, software (Applied Maths).

We collected 10 mL of blood from each participant in the case-control study to assess for serologic evidence of *V. cholerae* infection. At the CDC, serum samples were tested by a microtitration plate assay for vibriocidal antibodies and by an EIA for cholera toxin antibodies [2]. A vibriocidal antibody titer of >1:640 or a cholera toxin antibody titer of >1:200 was considered indicative of recent infection with *V. cholerae* O1. A serologically defined case patient met the clinical case definition and had serologic evidence of a recent *V. cholerae* O1 infection. A serologically defined control subject met the clinical control definition and had a vibriocidal antibody titer of <1:640 and a cholera toxin antibody titer of <1:200.

Environmental investigation. Using the *N,N*-diethyl-phenelyenediamine colorimetric method (Hach), we determined the chlorine concentration in water samples from the Kwajalein drinking water source used by Ebeyens, and we reviewed the records of water treatment for this source. At a grocery store on Ebeye, we obtained samples of 3 powdered drink mixes consumed by Ebeyens during the outbreak period. We reconstituted the drink mixes with distilled water and tested the solution using a model 7 pH meter (Corning Scientific Instruments).

Statistical analysis. We calculated maximum likelihood estimates of matched odds ratios (MOR) and their exact 95% CIs using EpiInfo version 6.04c (CDC). We calculated *P* values of ORs by the χ^2 method and Fisher's exact test. MORs with 95% CIs that excluded the value 1.0 and *P* values of <.05 were considered significant. To analyze socioeconomic status, we created composite variables, with 1 point given for the ownership of each car, freezer, or stove, and 1 point given for each room in the respondent's household. We used Student's *t* test of means to evaluate these scores and other continuous variables; differences with *P* values of <.05 were considered significant.

RESULTS

Between 1 December 2000 and 8 January 2001, there were 278 persons with the diagnosis of diarrhea were seen at the Ebeye Hospital, of whom 103 met our case definition for cholera (figure 2). Six case patients died, for a case fatality rate of 6%. The median age of the 103 persons meeting the cholera case definition was 28 years (range, 5–72 years); 55% of these patients were female. The time of onset of illness ranged from 1 December 2000 to 6 January 2001; the number of cases of illness onset peaked in late December (figure 2). The overall cholera attack rate was 1% (103 of 9345 individuals). Of these 103 case patients, 93 had known addresses. On the basis of these data, the attack rates, by administrative zone, were as follows: zone 1, 0.5% (12 of 2385 individuals); zone 2, 1% (32 of 2914 individuals); zone 3, 2% (49 of 2357 individuals) (figure 3). Four of the 6 deaths occurred among residents of zone 3,

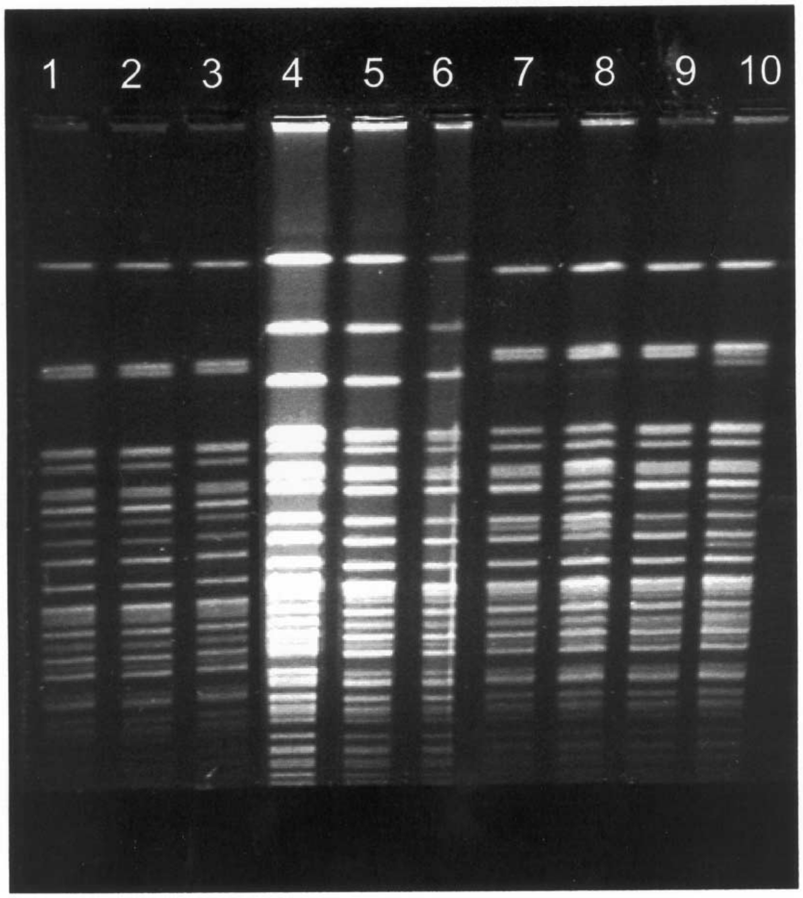

Figure 4. Pulsed-field gel electrophoresis patterns of *Vibrio cholerae* isolates from the Republic of the Marshall Islands (RMI) and the Federated States of Micronesia (FSM). *Lanes 1* and *2*, isolates from Ebeye Island, RMI, obtained in 2000. *Lane 3,* isolate from Lae Island, RMI, obtained in 2000. *Lanes 4–6,* isolates from Chuuk State, FSM, obtained 1982–1990. *Lanes 7–10,* isolates from Pohnpei State, FSM, obtained in 2000.

and 5 of the patients who died were females <50 years old. Five deaths occurred between 19 December and 25 December 2000, during the peak of the outbreak (figure 2).

Of the 103 persons with cholera, we were able to enroll 53 index case patients in the case-control study. Their median age was 32 years (range, 8–68 years), and 54% of these patients were female. Symptoms included watery diarrhea (in 98% of these 53 patients), vomiting (in 62%), nausea (in 60%), and abdominal pain (in 60%). We were able to enroll 104 control subjects; 51 case patients were matched to 2 control subjects, and 2 case patients were matched to 1 control subject each. There were no significant differences in age, sex, ethnic origin, household size, or socioeconomic status between case patients with cholera and control subjects.

Case patients had significantly greater odds of having collected water from the Kwajalein military base as the primary drinking water source during the 5 days before onset of diarrhea (MOR, 4.56; 95% CI, 1.08–39.99; $P = .02$) (table 1) and had significantly lower odds of having consumed primarily rainwater (MOR, 0.08; 95% CI, 0.00–0.69; $P < .01$) (table 1). Case patients also had significantly greater odds than control subjects of having used any water from the Kwajalein military base in the 5 days before illness (MOR, 8.00; 95% CI, 1.24–335.48; $P = .01$) and had significantly lower odds of having used any bottled water (MOR, 0.08; 95% CI, 0.02–0.22; $P < .01$) or any rainwater (MOR, 0.17; 95% CI, 0.03–0.67; $P < .01$). We could not assess consumption of Ebeye municipal water because only 3 persons reported this exposure.

Among persons who reported drinking water from the Kwajalein military facility during the time period of interest, use of an insulated water cooler with a spout to either transport or store water from Kwajalein was significantly associated with reduced odds of illness (MOR, 0.24; 95% CI, 0.09–0.58; $P < .01$). Use of open vessels or vessels with loose-fitting lids was not associated with increased odds of illness. Using a spout to transfer or remove drinking water from a container was also associated with reduced odds of illness (MOR, 0.36; 95% CI, 0.14–0.83; $P < .01$). No significant association was found between using other methods to transfer or remove water from a container and illness.

Table 2. Markers of socioeconomic status of case patients and control subjects during an outbreak of *Vibrio cholerae* O1 on Ebeye Island, December 2000, by cholera definition group.

	Clinical definition of cholera			Serologic definition of cholera		
Socioeconomic variable	Case patients	Control subjects	*P*	Case patients	Control subjects	*P*
No. of rooms in household						
Mean ± SD	2.40 ± 1.13	2.72 ± 1.27	.13	2.39 ± 1.2	2.80 ± 1.3	.10
Range	1–5	1–8		…	…	
Composite wealth score[a]						
Mean ± SD	4.19 ± 1.48	4.58 ± 1.51	.14	4.17 ± 1.52	4.67 ± 1.53	.11
Range	2–7	2–11		…	…	

[a] Composite wealth score was determined by giving 1 point for each car, freezer, or stove owned by the respondent and 1 point for each room in the respondent's household.

Drinking boiled water was significantly associated with reduced odds of illness (MOR, 0.47; 95% CI, 0.22–0.98; $P = .02$), as was drinking water flavored with powdered drink mixes (MOR, 0.18; 95% CI, 0.18–0.37; $P < .01$). Consumption of fruits and vegetables, eggs, beef, salt fish, crab, and pancakes were also associated with reduced odds of illness (table 1). All persons interviewed ate rice. No significant association was found between illness and consumption of leftover rice at room temperature or consumption of fermented breadfruit.

Relative odds of illness were neither significantly increased nor decreased by eating food prepared by a friend, neighbor, or relative not living in the respondent's home; by purchasing and eating food prepared outside the home; by eating food with one's hands; by washing one's hands before meals; by eating food prepared by a friend or relative off island and transported to Ebeye; by attending a social gathering; by eating food leftover from a social gathering; by traveling off Ebeye; or by hosting a visitor from another island. Neither cleaning raw sewage from streets nor swimming in the lagoon were associated with increased odds of illness. Illness was also not associated with caring for ill persons who had been diagnosed with cholera at Ebeye Hospital. Having heard a radio program about cholera was significantly associated with reduced odds of illness (MOR, 0.31; 95% CI, 0.14–0.70; $P < .01$).

Microbiologic investigation. The 3 original *V. cholerae* isolates were sent to the CDC and were found to be resistant to furazolidone, sulfisoxazole, and streptomycin, but sensitive to ampicillin, tetracycline, trimethoprim-sulfamethoxazole, chloramphenicol, kanamycin, nalidixic acid, and ciprofloxacin. PFGE subtyping indicated that these 3 isolates were indistinguishable from one another. However, they differed from isolates obtained during the recent cholera outbreak in FSM, as well as from isolates collected during previous cholera outbreaks in the FSM (figure 4).

Between 7 January and 1 March 2001, rectal swab samples were collected from 27 persons, comprising 52% of all patients presenting with diarrhea to Ebeye Hospital. *Vibrio cholerae* O1 was not isolated from any of these 27 stool specimens.

Serologic investigation. Sixty-nine percent of clinical case patients and 9% of control subjects had serologic evidence of *V. cholerae* infection. Reanalysis of the case-control data using the serologic case definition produced results that were consistent with the analysis made on the basis of the clinical case definition (tables 1 and 2).

Environmental investigation. The World Health Organization recommends that, during a cholera outbreak, the free chlorine concentration in piped water be >0.5 mg/L. We collected water from the Kwajalein military base water source used by Ebeye residents for drinking water during the period 3–18 February 2001, and monitored chlorine levels. The mean daily free chlorine level was 2.1 mg/L (range, 0.8–3.2 mg/L). Records indicated adequate chlorination of the water from this same source for the period November 2000–January 2001. Following identification of the outbreak in December, the military base increased the chlorine content of their water by 20%.

The pH of 3 powdered drink mixes used by Ebeyens ranged from 3.4 to 3.9. According to Kwajalein water plant records, water hardness averaged 51.3 mg of calcium carbonate per L during the outbreak period.

DISCUSSION

An outbreak of toxigenic *V. cholerae* O1 infections occurred on Ebeye and Lae Islands, RMI, during December 2000–January 2001. Cholera has not been previously described in the RMI. The origin of the outbreak was not determined. The PFGE patterns of *V. cholerae* isolates from patients on Ebeye and Lae Islands indicate that the same bacterial strain caused disease on both islands. This strain was significantly different from the strains isolated during a cholera outbreak in the Federated States of Micronesia earlier in 2000.

An epidemiologic investigation conducted on Ebeye Island demonstrated an overall attack rate of 1%, with a case-fatality rate of 6%. Notably, deaths occurred well into the outbreak, among young and otherwise healthy adults. In reviewing medical records and interviewing staff and families, we found no evidence that any death resulted from a lack of materials necessary for appropriate rehydration therapy. Delay in seeking care is a frequently cited risk factor for death in cholera outbreaks [5, 6]. Whether such delays contributed to deaths in this outbreak could not be determined, although, in this cholera-naive community, such delays may have been likely.

Our case-control study indicated that drinking water from the US military installation on Kwajalein was significantly associated with illness and that consuming rainwater, bottled water, or water that had been boiled was protective. We also found that transporting and storing adequately chlorinated drinking water in vessels that could be tightly sealed and from which water could be removed without opening the vessel (e.g., insulated water coolers with spouts) was protective. These characteristics have been shown to effectively reduce water contamination in other settings [7].

Water from the military installation on Kwajalein was the primary source of drinking water for Ebeye residents. Several respondents indicated that there was no need to treat water from Kwajalein because it was already chlorinated. Contamination of this water likely occurred during transport and storage in loosely sealed vessels from which water was removed by opening the vessel. Because rainwater is scarce during periods of drought and bottled water is costly, public health resources may be best invested in teaching citizens means of safely transporting and storing water and simple means of disinfecting water, such as point-of-use chlorination.

Drinking water flavored with powdered drink mixes was protective in this outbreak. Several brands of powdered drink mixes were available on Ebeye, all of which contained citric acid and some of which also contained ascorbic acid. D'Aquino and Teves [8] added 2×10^7 to 3×10^7 *V. cholerae* organisms per mL to water of a hardness similar to that of the water found on Kwajalein. They found that this water was sterilized in 15–30 min when maintained at the same pH values as the drink-mix–flavored water consumed by Ebeyens during the outbreak. Previous reports have noted that adding lemon and lime juices to drinking water has a protective effect against cholera [8, 9]. To the best of our knowledge, this study is the first to demonstrate that commercially available acidic drink mixes may protect against cholera. Powdered drink mixes should not be considered a routine option for cholera prevention; they contain excess sugar and may be confused with oral rehydration salts. They should be considered as an option of last resort when water cannot be boiled, chlorinated, or acidified with local fruits in the home.

Consumption of fruits, vegetables, eggs, beef, and salt fish was protective against cholera infection. It is possible that consumption of these foods was a marker of a respondent's higher, more-protective socioeconomic status compared to that of respondents who did not consume these foods, which our assessment did not measure. Most of these foods were either imported or were local delicacies (e.g., salt fish) and, therefore, were comparatively more costly than other dietary staples (e.g., rice, chicken, or other fish).

Hearing a public health announcement over the radio about the cholera outbreak was also protective. Census data from 1999 indicates that 90% of Ebeye households have a radio. A local radio station on Ebeye provided public service announcements during the outbreak and opportunities for residents to ask questions. Previous studies have demonstrated the important role radio announcements can play in disseminating health information during a cholera outbreak [10] and in other settings [11].

Our clinical case definition correlated well with the serologic status of case patients and control subjects. Although the analysis using serologically confirmed case patients and control subjects had less statistical power, the results were consistent with the analysis made using the clinical case definition.

The outbreak on Ebeye Island ended in January 2001. Several factors may have contributed to its termination, including the dissemination of public health messages, an increase in the chlorine content of Kwajalein water used by Ebeye residents, the cholera vaccination campaign, and the exhaustion of the number of susceptible individuals through either infection or vaccination. Active surveillance was continued throughout the RMI through March 2001, and no further cases of cholera were diagnosed.

In summary, this report describes the first known outbreak of cholera in the RMI. Illness was associated with drinking water from an adequately chlorinated source that was presumed safe. Transporting and storing this water in a vessel that could be securely sealed to retard evaporative loss of chlorine and to prevent introduction of bacterial contamination was protective. Although boiling water, using bottled water or rainwater, and adding powdered drink mixes to water were also protective against illness, these options may not be practical or affordable in resource-limited settings, such as Ebeye Island. Providing a safe water source can be insufficient to prevent cholera transmission if the means for safe transport and storage of water are not available.

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