Waterborne Cholera in Riohacha, Colombia, 1992[1]

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Between 1 January and 31 July 1992 a cholera epidemic caused 548 reported cases (an incidence of about 8 cases per 1 000 inhabitants) in Riohacha, Colombia. Following an initial review of hospital and laboratory data, a cross-sectional household survey and case-control study were conducted to investigate this epidemic.

The cross-sectional survey found an increased risk of cholera between November 1991 and September 1992 among subjects who usually drank unchlorinated piped water from the municipal water system (prevalence odds ratio, POR = 5.7; 95% confidence interval, CI = 1.2–41.1), as well as an increased risk of acute diarrheal disease in the 2 weeks preceding the survey interview among these same subjects (POR = 3.3; 95% CI = 1.1–11.2).

The case-control study revealed an association between cholera and drinking unboiled tap water (OR = 7.2; 95% CI = 1.6–32.2), and also between cholera and limited availability of water (<1 400 liters per week) within the household (OR = 3.6; 95% CI = 0.8–16.4).

These findings strongly suggest that most of the Riohacha cholera cases were transmitted by contaminated municipal water, a conclusion supported by descriptive evidence of problems affecting Riohacha's municipal water and sewerage systems.

Consumption of contaminated unboiled municipal water is thought to provide the main pathway for cholera transmission in Latin America's current cholera epidemic (*1*). However, only a few published reports from Latin America can be cited to support this statement (*2, 3*). Feachem, who thoroughly reviewed the 1961–1980 cholera literature (including 60 reports from 20 countries) found only three studies demonstrating or strongly implicating waterborne transmission. (The same review found 11 studies of situations where waterborne transmission was shown to be impossible or unlikely) (*4*).

In Colombia, about 30 000 cholera cases (approximately 1 per 1 000 inhabitants) and 500 deaths from cholera were reported to the Colombian Ministry of Health between 5 March 1991 and 1 September 1992. Case rates in coastal areas, however, were often much higher than those commonly found in the interior. One such coastal area, the Department of La Guajira on the Guajira Peninsula, reported 3 000 cases among its 320 000 inhabitants in the same period, indicating a rate almost 10 times higher than that prevailing nationally.

The capital of La Guajira Department, the port city of Riohacha, reported over 500 cholera cases among its 68 000 in-

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habitants between 1 November 1991 and 1 September 1992. (The cumulative cholera incidence among Riohacha's population was similar to that found elsewhere in the department.)

The Riohacha epidemic prompted local health officials to launch a department-wide massive house-to-house health education campaign. This effort, modeled on immunization campaigns, used volunteers to educate the public about cholera prevention and treatment. It was recorded that nearly 15 000 households (34% of all Guajira Department households) were visited in mid-June.

Beginning in early September, a field research team from the Advanced Training Program in Applied Epidemiology (a collaborative undertaking of the Colombian National Institute of Health, the United States Centers for Disease Control and Prevention, and local Ministry of Health officials) conducted studies in Riohacha to describe the epidemic, obtain information about cholera in the community, evaluate the health education campaign's effects on people's knowledge, attitudes, and practices, and identify cholera transmission risk factors. This article reports results obtained through those studies.

MATERIALS AND METHODS

Cholera Case Data

We obtained data on Riohacha cholera cases by reviewing the local hospital and health department records. Since only one health facility in Riohacha (the Nuestra Señora de Los Remedios Hospital) had a cholera treatment unit, all the information available on local cases was obtained from patients seen at this hospital. The hospital's principal initial criterion for defining cholera cases, one or more watery stools plus dehydration, was applied only to patients over 4 years of age.

The hospital's data on cholera cases included the patient's age, sex, place of residence, date of admission, and degree of dehydration. The initial diagnosis of cholera was confirmed by culturing *Vibrio cholerae* serogroup 01 from the patient's feces by standard methods.

For purposes of the studies reported here, the case addresses found in the hospital records were used to create a spot map locating the residence of each patient, and the laboratory log listing of patients whose feces were cultured for *V. cholerae* was reviewed.

Water and Sewerage Data

Information on the water supply and sewerage system was obtained by interviewing the local environmental health officer, who had occupied that post for over 15 years. We also reviewed the locally available results of studies on drinking-water quality.

Cross-sectional Survey

A two-stage cluster sample of households was selected, in conformity with an equal probability sampling design (5). For this purpose a sample of 47 clusters (representing 8% of all households in Riohacha) was drawn up in the first stage. The households listed within each cluster were then enumerated, and 20% of them were chosen at random to arrive at a survey sample of at least 200 households. It was intended that this sample would include about 1.5% of the Riohacha population.

The homemaker or children's caretaker, or if this person was not at home an adult at least 15 years old, was interviewed, using a questionnaire adapted from one used in El Paso, Texas, for similar purposes (Dr. Robert Tauxe, CDC, personal communication).[5] Through this interview we obtained information about the household's food and water hygiene practices, source of drinking water, type of available waste disposal system, whether the drinking water was chlorinated or boiled in the home, household knowledge about cholera prevention and treatment, the presence or absence of diarrheal disease within the household during the 2 weeks preceding the interview, and the occurrence of cholera cases among household members from December 1991 to the time of the interview in September 1992.

The presence or absence of cholera was determined by asking the informant "Since November 1991 has anyone in this household had cholera?" The presence or absence of a diarrhea episode in the 2 weeks before the interview was determined similarly, such an episode being defined as an illness of at least 1 day's duration involving at least two liquid stools.

Inquiry was made regarding the household's source of drinking water, type of wastewater disposal system, and any changes made in the domestic treatment of water or food (i.e., boiling or chlorination of water, washing of fruit and vegetables) since the cholera epidemic began. Information about the household members' literacy, schooling, and other socioeconomic variables was also sought.

In addition, sera were collected from all subjects said to have had cholera since November, and also from a sample of people present in the survey households who were not ill. Vibriocidal antibodies to *V. cholerae* serogroup 01 (serotype Inaba) and anti-cholera toxin antibodies were titered by Elizabeth Castañeda at the Colombian National Institute of Health following a Göteborg University protocol (*6, 7*). Serum specimens yielding titers >1:640 for vibriocidal antibodies and >1:64 for cholera toxin antibodies were considered positive.

[5]A copy of these questionnaires can be obtained from the first author (Víctor Cárdenas, see footnote 1).

Case-control Study

To reinforce the findings of the cross-sectional survey and further investigate the Riohacha epidemic, a case-control study was conducted. For purposes of this study, it was assumed as working hypotheses that cholera was transmitted by municipal water throughout the epidemic period and that prevailing food and water consumption patterns remained unchanged.

Cholera cases were selected for inclusion by systematic random sampling of all the cholera patients shown on the hospital records whose complete addresses were available, who were at least 5 years old when admitted to Nuestra Señora de Los Remedios Hospital, and who were discharged with a diagnosis of cholera between 1 January and 31 July 1992. All the selected controls were people at least 5 years old who were randomly selected from among those present during a second visit to households in the cross-sectional survey sample described above.

Information collected about both case and control subjects included their consumption of raw and cooked seafood; their consumption of food purchased from street vendors; their attendance at parties and funerals; cholera cases afflicting others within their households; their literacy, last grade of school attended, and other socioeconomic variables such as ownership of a home or car; and their access to household water, a flush toilet, latrines, soap, and other sanitary resources.

For the purpose of investigating cholera cases among study subject contacts in the case and control households, an index case within a case household was defined as another case of cholera in the household that occurred 2 or more days before that of the case subject; while an index case within a control household was defined as any cholera case within the household regardless of timing.

Water used in the households of case and control subjects was classified according to the cross-sectional survey data into the following categories: (1) water used for drinking and cooking; (2) water used for hygiene (to bathe, wash hands, brush teeth, rinse mouths, and flush toilets); and (3) water used for housekeeping. The sizes and volumes of water containers and reservoirs were estimated in order to define the total amount of water available to each study household.

Statistical Analysis

Data from the cross-sectional survey and case-control study were coded and then entered into a computerized database management system for analysis. Recorded cases were cross-tabulated and case rates were obtained using estimates based upon the latest population census. Comparisons between rates were made using exact binomial confidence intervals, the group experiencing the lowest rate being used as the referent. Point and standard errors of ratios were obtained using appropriate estimators for cluster sampling (*5*).

The geometric means of antibody titers were computed and compared using a one-way (single classification) analysis of variance (*8*), so as to obtain two-tailed p values. Exploratory analyses and simple comparisons were followed by stratified analysis entailing calculation of the exposure odds ratio, its 95% confidence interval, and the Mantel-Haenszel summary odds ratio (*9*) computed using the Robins, Greenland, and Breslow variance estimator (*10*). Exact mid-p values and confidence limits were calculated implying a polynomial algorithm developed by Martin and Austin (*11*), using a multiple hypergeometric distribution in the case of tables with a size larger than 2×2. Breslow and Day tests for statistical interaction were used in the stratified analysis (*12*), and a multiple logistic regression analysis was conducted to overcome limitations of the stratified analysis (*13*). Variables that were associated with the outcome were included alone in the model, and were then included with the source of drinking water, following the criteria of change of estimate as described by Greenland (*14*).

Age was treated as a categorical variable, and the trend over increasing levels of age was assessed using orthogonal contrasts. Potential confounders such as age and the occurrence of another case in the household were included in the model; the model's goodness of fit was assessed using the Hosmer-Lemeshow test (*15*).

RESULTS

Descriptive Epidemiology

Cholera cases began to occur among Riohacha residents toward the end of November 1991. Between 1 January and 31 July 1992, 548 cases were reported for a cumulative 1992 incidence of approximately 8 cases per 1 000 inhabitants. (Our field investigation took place in late September, after cholera transmission in Riohacha had stopped.) The data in Table 1 show that the reported rates increased significantly with age, but that both genders were about equally affected.

V. cholerae, biotype El Tor, serotype Inaba was isolated from 223 subjects residing in Riohacha during the period from 1 November 1991 to 1 August 1992. Laboratory reports showed that *V. cholerae* was isolated from 22 (20.6%) of 107 stool specimens obtained from children under 5 years of age, as compared to 201 (41.1%) of 489 stool specimens obtained from

Table 1. Reported cases of cholera and risks (cases per 1 000 inhabitants) by age and gender, Riohacha, Colombia, January–September 1992.

Age group (in years)	Cases						Risks (cases per 1 000 inhabitants)			Age group risk ratios (exact CI)
	Males		Females		Total					
	No.	(%)	No.	(%)	No.	(%)	Males	Females	Total	
<1	4	(0.7)	10	(1.8)	14	(2.6)	4.8	12.1	8.5	1.8 (1.0–3.3)
1–4	26	(4.7)	25	(4.6)	51	(9.3)	6.5	6.2	6.3	1.3 (0.9–2.1)
5–9	35	(6.4)	25	(4.6)	60	(10.9)	7.5	5.4	6.4	1.4 (0.9–2.1)
10–14	34	(6.2)	16	(2.9)	50	(9.1)	7.1	3.3	5.2	1.1 (0.7–1.7)
15–19	20	(3.6)	17	(3.1)	37	(6.7)	5.1	4.2	4.6	1.0, referent
20–29	60	(10.9)	56	(10.2)	116	(21.2)	11.1	9.5	10.3	2.2 (1.5–3.2)
30–39	48	(8.8)	40	(7.3)	88	(16.0)	15.9	10.8	13.0	2.8 (1.9–4.2)
40–49	24	(4.4)	30	(5.5)	54	(9.9)	8.6	11.2	9.9	2.1 (1.4–3.2)
50+	37	(6.8)	41	(7.5)	78	(14.2)	13.8	15.4	14.7	3.2 (2.1–4.7)
Total	288	(52.5)	260	(47.5)	548	(100.0)	8.4	7.6	8.0	

people over 5 years old ($p < 0.0001$, Z test for proportions).

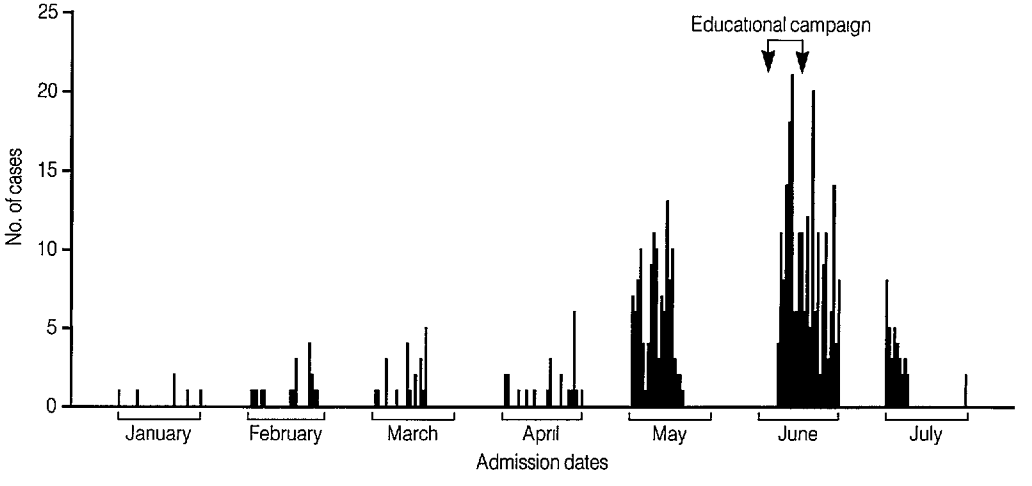
Figure 1 charts the cases occurring from 1 January through 31 July 1992. The decline in the epidemic occurred after the education campaign in early July.

Due to incomplete patient address data in the hospital records, the patient's place of residence was obtained for only 28.3% of the 548 subjects diagnosed with cholera. Figure 2 shows a map of Riohacha on which these residences are located. As may be seen, all neighborhoods in the city were affected. However, case rates were significantly higher on the outskirts of the city (rate ratio = 1:7.5; 95% CI = 2.9–19.8) and just to the west of the mouth of the Ranchería River.

Water and Sewerage System

The Riohacha water system supplies 150 liters of water per second, which is obtained from six deep wells and from

Figure 1. Cholera cases admitted to Riohacha's Nuestra Señora de Los Remedios Hospital in January through July 1992, by date of admission. The arrows indicate the period of the anti-cholera education campaign in Riohacha.



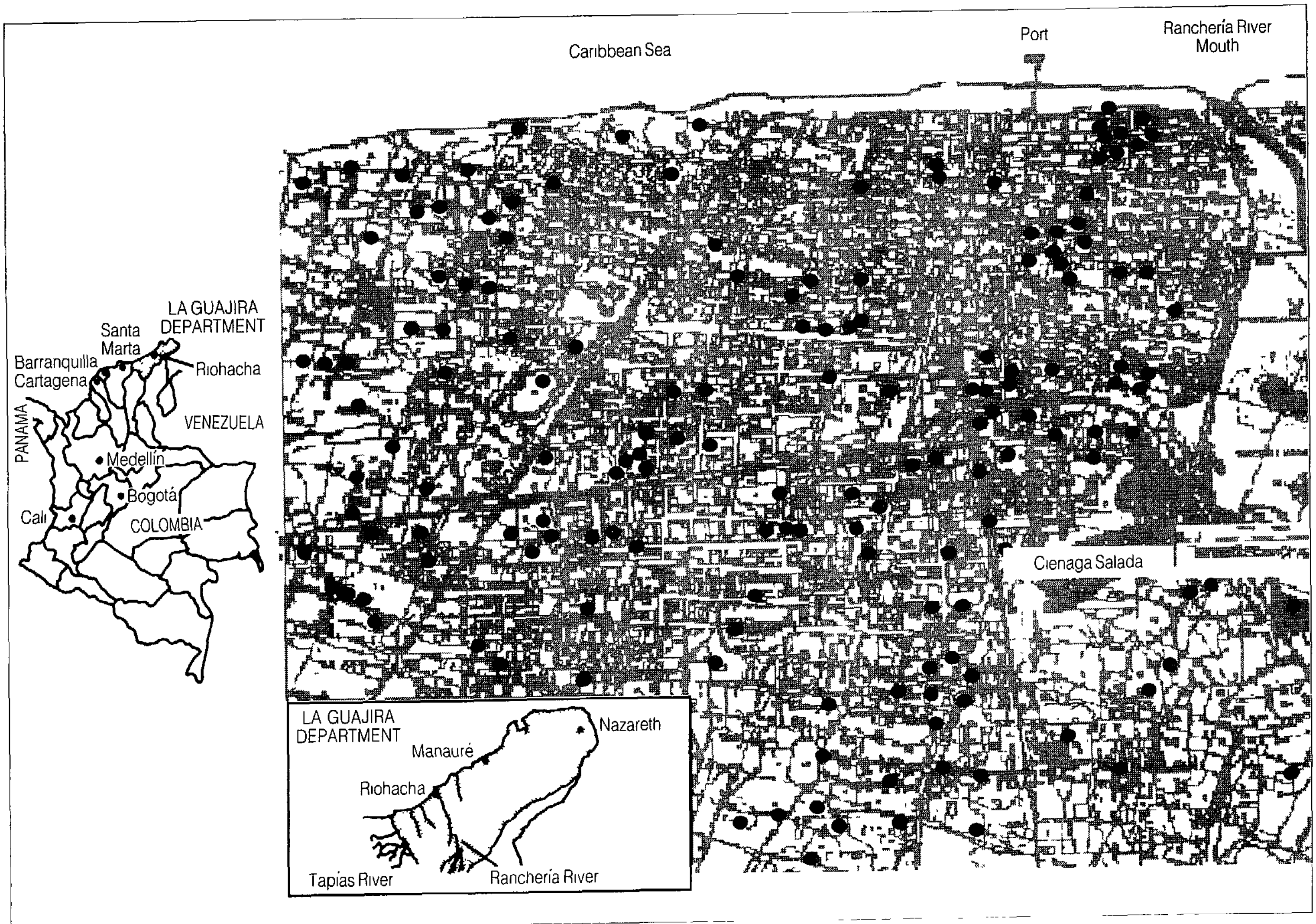


Figure 2. A map of Riohacha showing the residence places (black dots) of those cholera patients whose complete addresses were obtained from hospital records. ● = 1 case.

the surface of the Tapias River, upstream of the place where Riohacha wastewater is discharged. The casings of the six wells are believed to be defective. Both the well and surface water are mixed and treated but not chlorinated at the local water plant. Levels of chloride in the municipal drinking water range from 300 to 600 mg/L, probably because of seawater intrusion. About 70% of Riohacha's households receive municipal water through the piped water distribution system, while the remainder receive it from water trucks.

Sewage contamination of the municipal water supply has been reported. This is said to be caused by leaking of municipal water in the old part of the city, cracks in the pipelines, lack of pressure (and consequent negative pressure) in the distribution system, and improper distances between sewerage system and water system pipelines (personal communication, Juan Bonivente, local environmental health official, Ministry of Health).

Three physical, chemical, and microbiologic studies of this municipal drinking water system were conducted between July and September 1992 at different points in the distribution system. Total coliform counts ranged from 600 to 3 500 organisms per 100 ml. Samples of commercial bottled water were similarly tested on 26 October 1992. These were found to contain less than two coliform organisms per 100 ml. This commercial drinking water came from the Jérez River, which together with the Tapias River flows into the Caribbean, and was treated with aluminum sulphate and calcium hypochlorite (report issued by Dr. Rafael Iguarán Bado, Ministry of Health).

Cross-sectional Survey

A total of 209 households were selected from among the 47 housing clusters for inclusion in the survey. Over three-quarters (76.9%) of the respondents interviewed in these households were homemakers.

As Table 2 indicates, nearly half (45.9%, 95% CI = 40.0–51.8) of the respondents said their households were visited in the course of the cholera education campaign. About half (49.5%, 95% CI = 43.4–55.6) also reported that the household's drinking water was boiled. In 39% of the households only containerized water was consumed, while in the remainder, raw water (municipal or private, river or well water) was drunk. Of those households consuming the municipal water, only 40% were said to regularly boil their drinking water.

Overall, the survey found a cumulative cholera incidence of 8 cases per 1 000 inhabitants since November 1991, a figure in agreement with local data. The reported prevalence of diarrheal disease in the 2 weeks preceding the survey varied greatly by age, being almost 25% among infants but less than 3% among all other age groups. In contrast, the respondents reported no episodes of cholera among the survey household infants (Table 3).

A vast majority of the respondents (see Table 2) were aware of the two major cholera symptoms (diarrhea and vomiting), and only 11% were unable to state any symptom. While the respondents indicated that their information came from various sources, many (68% and 72%, respectively) cited television and radio announcements. Methods traditionally used by local health services (informative leaflets and educational posters, newspaper advertisements, loudspeaker announcements, and meetings at health units or neighborhood meetings) were infrequently mentioned as sources of cholera information by 21.9%, 7.8%, 13.7%, and 23.8% of the respondents, respectively.

Respondents' beliefs and practices with respect to boiling drinking water were found to be consistent. That is, of the 94 respondents who said their household

Table 2. Main findings other than disease cases of the September 1992 cross-sectional survey of 209 households in Riohacha. In general, the base used to derive the percentages shown was less than 209, because not all the respondents provided usable answers to the particular question asked.

Variable	Households No.	Households % (95% CI)
Reported visits during massive health education campaign	*95*	*45.9 (40.0–51.8)*
Source of drinking water:[a]		
River	25	12.7 (9.0–16.4)
Private wells	10	5.1 (2.9–7.3)
Municipal water:		
Piped water	*77*	*39.1 (33.8–44.4)*
Water truck	*12*	*6.1 (3.4–8.8)*
Bottled water:		
Glass container	*72*	*36.5 (31.0–42.0)*
Plastic bag	*6*	*3.0 (1.0–5.0)*
Storage of drinking water in buckets/pool/sink/barrel	*59*	*37.3 (31.0–43.6)*
Cholera-associated symptoms known by household respondents:		
Diarrhea	174	89.2 (85.3–92.1)
Vomiting	168	86.2 (81.9–90.5)
Dehydration	32	16.4 (11.9–20.9)
Cramps	24	12.3 (8.4–16.2)
Death	2	1.0 (0–2.4)
Do not know	15	7.7 (4.6–10.8)

[a]As the figures suggest, there was some overlap in the categories listed under this heading.

Table 3. Diarrheal disease cases indicated by liquid stools in the 2 weeks preceding the survey and cholera cases since November 1991 that were reported by the household respondents in the cross-sectional survey.

Age group (in years)	Diarrheal disease cases (liquid stools) in 2 weeks before interview		Cholera cases (diarrhea + dehydration) since November 1991	
	No.	% of age group	No.	% of age group
<1	7	24.1	0	0.0
1–4	3	2.1	1	0.7
5–9	1	0.6	1	0.6
10–14	3	1.7	2	1.1
15–49	2	0.3	4	0.6
50+	3	3.2	2	2.1
Total	19[a]	1.5	10[b]	0.8

[a]15 households with cases.
[b]9 households with cases.

drinking water was boiled, 71 (75%) mentioned this as an effective way of preventing cholera. In contrast, of the 95 who said their household drinking water was not boiled, only 32 (33%) cited this measure as effective in preventing cholera ($p < 0.0001$ for a χ_1^2).

Nearly all the respondents said that in the event of becoming ill with cholera symptoms they would have sought care for cholera at a hospital or clinic. However, when asked about what they could have done to prevent the illness, most simply said they would have sought attention at a health unit, and many reported not knowing what to do to prevent it.

When the household survey results were analyzed with cholera and diarrheal disease cases as outcome variables, a consistent association was found between both types of cases and drinking municipal water (Table 4). Conversely, consumption of bottled water and boiling of drinking water were both found to be protective. No associations were found between diarrhea or cholera and regular consumption of food from street vendors. According to local epidemiologists, raw seafood ("ceviche") was not normally consumed in the area, a fact confirmed by failure of any of the survey respondents to cite the practice.

The data shown in Table 5 suggest that the education campaign significantly increased public awareness of oral rehydration salts' effectiveness in treating cholera. Indeed, those who said they were visited by volunteers during the campaign were twice as likely as those who said they were not visited to cite ORS as the treatment of choice for cholera.

Vibriocidal antibodies and IgG anticholera toxin were titered against serum specimens from five subjects shown by the household survey to have had cholera since November 1991, seven household survey subjects with diarrhea in the 2 weeks preceding the interview, and 15 subjects in neither of these groups. The sera from all five cholera cases yielded vibriocidal antibody titers ≥1:1 280, while none of the other 22 sera showed a titer >1:640 ($p = 0.000012$) (Figure 3). Regarding the IgG anti-cholera toxin, this gave a geometric mean titer of 1:1 940.1 (standard deviation = 1.46) when tested against the five cholera case sera, as compared to 1:32.8 (SD = 3.25) and 1:48.1 (SD = 4.6) versus the seven diarrhea case sera and 15 healthy subject sera, respectively, yielding a statistically significant difference ($F_{2,24} = 17.145$, $p < 0.001$).

Case-control Study

Thirty-two cases or 65% of our random sample of those discharged from the hospital with a diagnosis of cholera during January–July 1991 were included in the study. The reasons for not including the remaining 17 cases were an incomplete or incorrect address or absence of the subject from the home at the time of the study visit. In addition, 38 controls were selected in the manner described above.

As the figures in Table 6 show, the case subjects tended to be younger than the control subjects ($p < 0.01$). However, the two groups did not differ significantly with respect to gender, ethnic background, consumption of seafood, consumption of food sold by street vendors, attendance at burials, occupation, consumption of boiled versus unboiled drinking water, and the presence or absence of a refrigerator in the home. A marginally significant difference ($p = 0.07$) was found between the two groups with respect to education (the last school grade attended). More critically, clear and significant differences were found between the two group's use of municipal water for drinking (OR = 3.6), the availability of water in their households (OR = 2.3), and occurrence of an index case in the

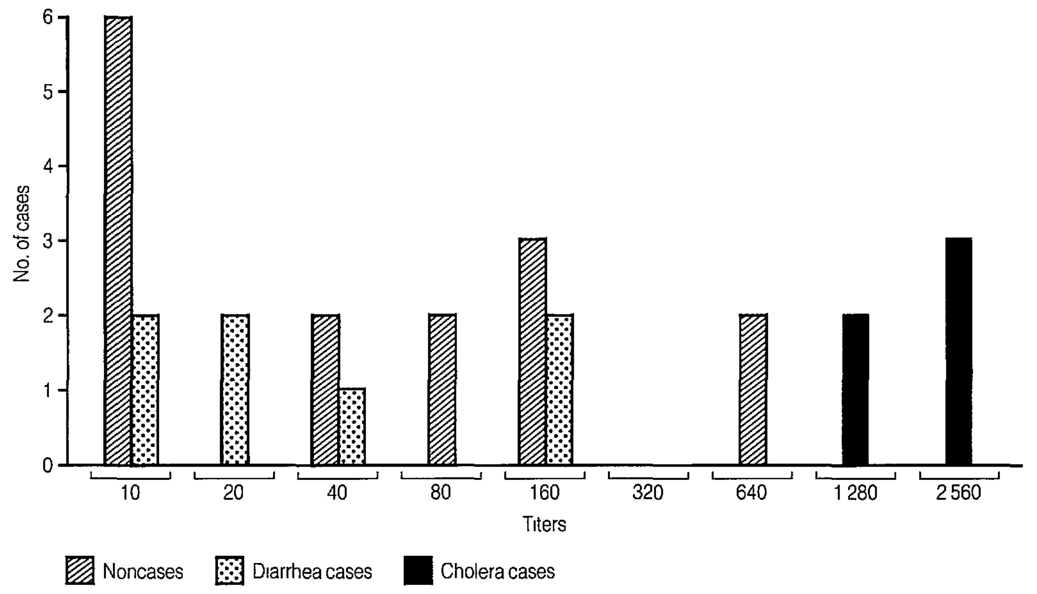
Table 4. Results of analyzing the cross-sectional household survey data for correlations between the variables listed at the left and the occurrence of diarrheal disease (within 2 weeks of the interview) and cholera (since November 1991). In many cases the total number of households used to derive the figures was less than 209 because not all the respondents provided answers usable in the analysis. Regarding the odds ratios shown at right, DD = diarrheal disease, CHOL = cholera.

	Survey households reporting:								
	Diarrhea <2 weeks before interview		Cholera since November 1991		No diarrhea <2 weeks before interview		No cholera since November 1991		
	Households exposed to variable shown		Households exposed to variable shown		Households exposed to variable shown		Households exposed to variable shown		
Variable	No.	(%)	No.	(%)	No.	(%)	No.	(%)	Prevalence odds ratio (95% CI)
Source of water:									
Municipal water	*10*	*(66.7)*	*7*	*(77.7)*	*67*	*(37.4)*	*68*	*(37.8)*	*3.3 (1.1–11.2) DD* *5.7 (1.2–41.1) CHOL*
Bottled water	*2*	*(13.3)*	*0*	*(0.0)*	*67*	*(37.4)*	*70*	*(38.9)*	*0.3 (0.0–1.0) DD* *0.0 (0.0–0.6) CHOL*
Drink boiled water:	5	(35.7)	4	(44.4)	88	(50.3)	87	(49.4)	0.6 (0.2–1.7) DD 0.8 (0.2–3.3) CHOL
Food from street vendors (the informant):	8	(53.3)	4	(44.4)	64	(36.0)	65	(36.3)	2.0 (0.7–6.1) DD 1.4 (0.3–5.7) CHOL
Illiteracy (of the informant):	1	(6.7)	2	(22.2)	30	(16.3)	28	(15.1)	0.4 (0.0–2.2) DD 1.6 (0.2–7.6) CHOL
Reported use of toilet paper:	11	(73.3)	8	(88.9)	159	(89.3)	155	(88.1)	0.3 (0.1–1.3) DD 1.1 (0.2–25.3) CHOL
House or car ownership:	4	(28.6)	2	(22.2)	68	(37.4)	67	(36.8)	0.7 (0.2–2.2) DD 0.5 (0.1–2.8) CHOL
House with refrigerator:	9	(60.0)	3	(33.3)	122	(68.2)	126	(70.0)	0.7 (0.2–2.2) DD 0.2 (0.0–0.9) CHOL

Table 5. Results of analyzing the cross-sectional household survey data for correlations between the variables listed at the left and the occurrence of visits to the survey households during the July 1992 health education campaign. In many cases the total number of households used to derive the figures was less than 209 because not all the respondents provided answers usable in the analysis.

	Survey households that were:				
	Visited during July 1992 campaign		Not visited during July 1992 campaign		
	Households with variable shown		Households with variable shown		
Variable	No.	(%)	No.	(%)	POR (95% CI)
Refrigerator present	69	(72.6)	65	(63.7)	1.5 (0.8–2.9)
Respondent did state main symptoms of cholera	18	(18.9)	13	(11.6)	1.8 (0.8–4.2)
Respondent did say oral rehydration salts are effective against cholera	72	(80.0)	63	(64.3)	2.2 (1.1–4.6)
Household drinking water is boiled	46	(50.5)	49	(48.5)	1.1 (0.6–2.0)
Household member owns house/car	62	(69.7)	64	(58.7)	1.6 (0.9–3.1)
Respondent's age (in years)	mean = 37.8		mean = 36.5		t-test, p = 0.6
Respondent's education (years of school)	mean = 7.7		mean = 6.1		t-test, p = 0.2

Figure 3. Vibriocidal antibody titers yielded by sera from 5 cholera patients, 7 acute diarrhea patients, and 15 apparently healthy subjects in Riohacha, September 1992.



household (OR = ∞, lower limit of the 95% CI = 1.6).

Stratified analysis showed that the effect of boiling the subjects' household drinking water varied according to the source of the water. Among those who drank municipal water, boiling the drinking water had a strong protective effect (OR = 0.35; 95% CI = 0.1–1.4); but among those who drank bottled water no effect was found (OR = 1.0; 95% CI = 0.2–5.8) (Breslow and Day χ_1^2, p = 0.29).

On the other hand, the effect of drinking municipal water was well above the null, whether the water was reportedly boiled (OR = 2.1; 95% CI = 0.4–12.4) or not (OR = 6.5; 95% CI = 1.6–26.6) before drinking. While a slight difference appeared consistently in the direction of what would be expected on biological grounds (i.e., more risk for those who did not boil the water), this difference did not attain statistical significance (Breslow and Day χ_1^2, p = 0.29). Therefore, we decided not to control for this variable and to employ the full data set in the absence of statistically significant interaction using either stratified analysis or statistical modeling.

Results of the logistic regression modeling are shown in Table 6. The effect of the drinking water source (municipal or other) was not confounded by age, gender, or any other covariate (OR = 7.2; 95% CI = 1.6–32.2). As mentioned above, cases had a different age distribution than controls. Simple analysis suggested a "bathtub-shaped" function, but use of orthogonal contrast in logistic regression failed to show a consistent trend.

For purposes of the logistic regression analysis, it was decided that the model should include (1) age, using the second age group (15–24 years) as referent, and (2) the occurrence of an index case in the subject's household. The resulting risk (odds ratio) estimates for drinking municipal water and having a water shortage in the household (<1 400 liters available per week), adjusted for covariance, are listed in the next to the last column of Table 6. The p value obtained with the Hosmer-Lemeshow test was 0.2, indicating insufficient statistical evidence to claim that the logistic model failed to fit the data.

DISCUSSION

The findings of our studies are consistent with the hypothesis that the municipal water system was contaminated and was serving as a key vehicle for cholera transmission. They are thus among the first ones published that implicate municipal water as a transmission vehicle during the recent Latin American cholera epidemic. (In a similar vein, studies conducted in Trujillo, Peru (*2*) concluded that "cholera control measures should focus on treatment of water and prevention of contamination during distribution.")

Before discussing the implications of these findings, however, it seems appropriate to review issues that could affect the validity of our studies. Cross-sectional studies of diarrheal disease have the advantage of being relatively free of disease misclassification. However, the potential ambiguity of the causal sequence (*16*) and the common 2 week recall period (though widely used) have been found to yield prevalences 30% below the apparent prevalence determined by other methods in some demographic and health surveys conducted in Latin America (*17*). Moreover, misclassification bias is likely to have occurred because of variation in patterns of food and water consumption, and because the timing of the study prevented us from doing a bacteriologic study of common sources.

All this points up one weakness of our studies, which is the lack of isolation of

Table 6. Results of the September 1992 case-control study of 32 subjects discharged from the hospital with a diagnosis of cholera during January–June 1992 and 38 control subjects randomly selected from among people present at a second visit to households included in the cross-sectional survey. Besides the basic data (numbers and percentages of cases and controls in particular categories) the table shows the results of statistical analyses (probabilities, odds ratios and 95% confidence intervals, and adjusted odds ratios and confidence intervals derived by logistic regression). Most of the case and control data shown are based on less than the total samples of 32 and 38 individuals because of missing observations.

Variable	Cases in indicated category		Controls in indicated category		Odds ratio (95% CI)	Results of logistic regression	Results of Fisher's exact test for 2 × k cells
	No.	(%)	No.	(%)		Adjusted odds ratio (95% CI)	
Age in years:							
5–14	*11*		*1*		*5.1 (2.1–1 133.2)*	*18.1 (1.2–267.0)*	
15–24	*5*		*11*		*1.0, referent*	*1.0, referent*	
25–34	*6*		*13*		*1.0 (0.2–5.5)*	*1.0 (0.1–9.8)*	*0.01*
35–44	*3*		*5*		*1.3 (0.1–10.5)*	*2.2 (0.3–19.9)*	
≥45	*7*		*8*		*1.9 (0.3–10.8)*	*0.7 (0.1–7.0)*	
Gender male	9	(39.1)	16	(43.4)	0.5 (0.2–1.5)	—[a]	
Index case present in household	5	(16.1)	0	(0.0)	∞ (1.6–∞)	∞ (0–∞)	
Drinking municipal water	22	(70.9)	15	(40.5)	3.6 (1.3–10.1)	7.2 (1.6–32.2)	
Shortage of water in household (<1 400 liters/week)	22	(68.7)	17	(48.5)	2.3 (0.9–6.4)	3.6 (0.8–16.4)	
Head of household engaged in fishing-related trades	2	(6.9)	1	(2.7)	2.7 (0.2–80.7)	—	
Drinking water boiled	18	(58.1)	20	(54.1)	1.2 (0.4–3.1)	—	
Toilet paper used	30	(93.7)	36	(100.0)	0.0 (0.0–3.6)	—	
Refrigerator in household	17	(56.7)	13	(56.5)	1.0 (0.3–3.1)	—	
Consumption of seafood (times/month)	mean = 5.5		mean = 8.6		t-test, p = 0.7		
Last year of school attended	mean = 6.5		mean = 8.2		t-test, p = 0.07		

[a]— = Variable not selected for inclusion in the model.

V. cholerae in the water system. No attempt was made to isolate *V. cholerae* from the water because no cases were reported while the team was in the field, and we assumed attempts at such isolation were unlikely to succeed.

It can also be argued that our measurement of sanitary practices was crude, but this lack of refinement in assessing relevant exposures and disease status would have tended to dilute the true association, biasing the results toward the null value, as has been shown analytically by several authors (*18*). Therefore, pursuit of this argument suggests that the cholera risk associated with drinking water from the municipal supply may have been so great that even studies possessing little statistical power and using usual water consumption patterns rather than actual water consumption on a case-by-case basis were able to detect it.

Recall bias could also have occurred in answers to questions about water supply and sanitation. For this reason, it is reassuring that a strong association was found between the occurrence of cholera and a shortage of water (<1 400 liters per week) available to the household, because the latter variable was determined by observation rather than by the reports of survey subjects. A related validity issue raised by Feachem (*4*) is that having less contaminated water available might be thought to reduce the risk of cholera, whereas our study findings suggest this increased the risk. In our view, this apparent contradiction could be explained by some or all of the water shortages being indicators of (1) back-siphonage in the water system or (2) increased salinity, which is a critical condition for growing *V. cholerae*.

It is important to note that the effects of drinking municipal water and having limited water available, as they are shown in the next to the last column of Table 6, are independent of one another, since all four variables[6] were entered in the same model. Therefore, even if limited water availability and within-household cholera transmission pointed to person-to-person transmission, municipal water contamination would still have played an important role.

Confounding by age and the communicable nature of cholera (i.e., nonindependence) was controlled for in the analysis, rather than by using the classical pair-matching approach (*19*). Even so, uncontrolled-for confounding might still have occurred. It could be argued, for instance, that the source of water and the quantity of water available could be surrogates of another variable linked with person-to-person cholera transmission. To help examine this matter we did collect information on variables such as home and car ownership, education, occupation, and availability of a flush toilet or latrine. No association between cholera transmission and any of these variables was found.

We also assessed the completeness of case detection in Riohacha and found no evidence of major underreporting. Since our controls were taken from a random sample of households, there appears to be no reasonable basis for a selection bias. In the absence of underreporting, our findings are consistent with highly effective disease surveillance during the epidemic's early stages.

Data from the cross-sectional survey and from control households in the case-control study consistently indicated that approximately 40% of the population covered was drinking municipal water. On the basis of these results and the estimated risk ratios obtained from both studies, we conservatively estimate that three-fourths of the cholera transmission

[6]Subject's age, drinking municipal water, <1 400 liters per week available to the household, and an index case present in the household.

in Riohacha could have been prevented by water sanitation. That is, estimating the odds ratio of the relative risk of drinking municipal water at 7.2 and the Riohacha cholera case incidence at 8 cases per 1 000 inhabitants, the incidence in the unexposed population would be 2 cases per 1 000 inhabitants [0.008/(7.2 × 0.4) + (0.6) = 0.002].[7] Therefore, the population attributable fraction, the proportional difference between the incidence in the general population and the incidence in the unexposed population, is 75% [(0.008 − 0.002)/0.008 = 0.75].

These results are consistent with exposure through mechanisms that have not been seen for decades, at least on the American Continent, perhaps because cholera has not been transmitted in urban settings of middle-income countries that have large but unsafe and inefficient municipal water systems. In other settings carefully conducted studies (*2–3, 20–22*) have documented that surface and drinking water contamination have led to cholera transmission. However, published epidemiologic information is not plentiful. In updating the review published by Feachem on documented epidemic and endemic transmission of cholera, we retrieved information indexed at the U.S. National Library of Medicine (MEDLINE) using the Medical Subjects Headings of "cholera," "epidemiology," and "transmission" from 1981 to 1992. This review, the results of which are listed in Table 7, turned up 16 situations in which water was not implicated as a transmission vehicle and another 10 in which water was mentioned. Only four studies of the latter group (those by Glass in Indonesia, Tauxe in Mali, Swerdlow in Peru, and Reiss in Peru) provided epidemiologically supported evidence of waterborne cholera transmission. When these reports are added to those of 1961–1980 that were reviewed by Feachem (*4*), it appears that published reports of nonwaterborne cholera transmission outnumber those citing waterborne transmission by a ratio of approximately 2.1:1.

One of the most compelling reasons for implicating Riohacha's municipal water supply in cholera transmission was the fact that drinking municipal water was found to be a risk factor for both acute diarrheal disease and cholera. This finding also underscores the fact that water can serve as a transmission vehicle for many diarrheal disease agents in the form of toxins, viruses, bacteria, and protozoa. Esrey et al. have reviewed the potential impact of improved water supply and sanitation on transmission of certain diseases (*23, 24*) and have concluded that a 65% reduction of childhood mortality can be achieved by such measures. Indeed if the associations reported here were causal, there would be a stronger argument for chlorinating municipal water in Latin America for the purpose of preventing not only cholera but also diarrheal diseases.

Prevalence (P) data can be used to obtain estimates of incidence (ID) using the relationship $P \div (1 - P) = ID \times$ mean d, where d is the duration of an episode. If the incidence of diarrhea were stable with a mean duration of 6 days, there would be 900 episodes per 1 000 person-years in Riohacha. Using our estimate of 3.3 for the prevalence odds ratio of diarrhea among those drinking municipal water, 431 of these episodes would have been due to the contaminated water system. This would make the incidence of endemic diarrhea attributable to contaminated municipal water in Riohacha 54 times the cholera incidence during the 1992 epidemic.

[7] $I_u = I_t/[(RR \cdot P_e) + P_u]$ where I_u is the incidence among the unexposed, I_t is the overall incidence, RR is the relative risk, P_e is the proportion exposed, and P_u is the proportion unexposed.

Table 7. Nonwaterborne and waterborne cholera documented in endemic and epidemic conditions, 1960–1991, as reported in sources reviewed by Feachem (*4*) or obtained through a literature search by the authors.

Area	Date of epidemic or study period	Biotype/serotype	No. of cases	Source of data
I. Waterborne source not implicated or food source implicated:				
Hong Kong	1961–1966	El Tor	238	Forbes, 1968
Malaysia	1969	El Tor/Inaba	Many	Dutt, 1971
Israel	1970	El Tor	250	Cohen, 1971
Sahelian countries	1970–1971	El Tor/Ogawa	10	Salmaso, 1980
South Africa	1970	El Tor/Inaba	Few	Isaacson, 1974
Phillipines	1971–1972	El Tor	Many	Velimirovic, 1975
Italy	1973	El Tor/Ogawa	278	Baine, 1974
Guam	1974	El Tor/Ogawa	6	Merson, 1977
Portugal	1974	El Tor	Many	Blake, 1977
Nauru	1977	El Tor	Many	Kuberski, 1980
Kiribati	1977	El Tor/Inaba	572	McIntyre, 1979
Bahrain	1978	El Tor/Ogawa	746	Gunn, 1979
Japan	1978	El Tor	18	Fukumi, 1980
United States of America	1978	El Tor	11	Blake, 1980
Italy	1979	El Tor/Ogawa	10	Salmaso, 1980
Truk	1980	*V. cholerae* 01	Many	Holmberg, 1984[a]
Guinea	1980	El Tor	Many	St. Louis, 1990[a]
Italy	1980	*V. cholerae* non 01	Many	Piergentli, 1984[a]
Bangladesh	1982	*V. cholerae* 01	Many	Khan, 1984[a]
Singapore	1982	*V. cholerae* 01	37	Goh, 1984[a]
Bangladesh	1982	*V. cholerae* 01	Many	Craig, 1988[a]
Mozambique	1983	El Tor	205	Cans, 1986[a]
United States of America	1986	*V. cholerae* 01	18	Lowry, 1989[a]
Thailand	1987	El Tor/Inaba	59	Swaddiwudhipong, 1989[a]
Thailand	1987	El Tor/Inaba	15	Swaddiwudhipong, 1990[a]
Thailand	1987	El Tor/Inaba	74	Swaddiwudhipong, 1991[a]
Singapore	1988	El Tor/Ogawa	74	Gohkt, 1990[a]
II. Waterborne source implicated:				
Portugal	1974	El Tor/Inaba	Many	Blake, 1977
Bangladesh	1970–1976	El Tor	Many	Hughes, 1982
Australia	1977	El Tor/Inaba	2	Rogers, 1980
South Africa	1981	*V. cholerae* 01	Many	Sinclair, 1982[a]
Palestine	1981	El Tor/Ogawa	Many	Lasch, 1984[a]
United States of America	1982	El Tor/Inaba	16	Johnstone, 1983[a]
Indonesia	1982	*V. cholerae* 01	138	Glass, 1984[a]
Nigeria	1983	El Tor/Ogawa	Many	Umoh, 1983[a]
Mali	1984	El Tor/Ogawa	1 793	Tauxe, 1988[a]
Malawi	1988	El Tor/Inaba	951	Moren, 1991[a]
Azerbaijan	1990	El Tor/Ogawa	2	Grizhebovski, 1991[a]
Peru	1991	El Tor/Inaba	16 400	Swerdlow, 1992[a]
Peru	1991	El Tor/Inaba	Many	Reiss, 1992[a]

[a]Published source retrieved by the authors' review of indexed MEDLINE data. A complete bibliographic listing of these sources is available from the authors upon request.

On the other hand, we do not imply that person-to-person cholera transmission or transmission by water contaminated within the household played no role in the 1992 epidemic, or that bottled water is necessarily safe. In this regard it is worth noting the results of one field study showing that water in plastic bags distributed in Mexico City after the 1985 earthquake caused diarrhea (*25*). However, our study findings do firmly support the idea that the municipal water supply system was likely to have been involved in the transmission of cholera in Riohacha. Accordingly, we have strongly recommended to the public health authorities in Riohacha that construction work at the new chlorination plant there be completed, and that more investment be devoted to updating and maintaining the water supply and sewerage systems.

More generally, the public health implications of studies like this linking lack of basic sanitation to cholera transmission lend further justification to the already urgent need to upgrade and maintain water and sewerage systems (*1, 26–27*). Indeed, there is need for a sanitary reform in most Latin American countries similar to the one that took place in Europe in the second half of the nineteenth century, precisely in response to cholera.

A report published in 1991 (*28*) stated that 33.8 million people living in urban areas of Latin America, and another 55.5 million in rural areas, lacked access to a water supply, and that "75 percent or more of the water supply systems did not disinfect at all or had serious operational problems that interfered with effective and continuous disinfection." Within this context, it appears that Latin American public health practitioners, particularly epidemiologists, have both an opportunity and a moral obligation to carry out timely investigations identifying these and other cholera transmission pathways, thereby paving the way for effective control measures.

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REFERENCES

1. Glass RI, Libel AD, Brandling-Bennett AD. Epidemic cholera in the Americas. *Science.* 1992;256(5063):1524–1525.
2. Swerdlow DL, Mintz ED, Rodríguez M, et al. Waterborne transmission of epidemic cholera in Trujillo, Peru: lessons for a continent at risk. *Lancet.* 1992;340: 28–33.
3. Reiss AA, Vugia D, Bengolea A, et al. Epidemic cholera in Piura, Peru: the hazards of commercial ice, municipal water, and street vendors. In: American Society for Microbiology. *Abstracts of the 31st Interscience Conference on Antimicrobial Agents and Chemotherapy.* Washington, DC: 1991. (Abstract 10).
4. Feachem RG. Environmental aspects of cholera epidemiology; I: a review of selected reports of endemic and epidemic situations during 1961–1980. *Trop Dis Bull.* 1981;78(8):675–698.
5. Levy PS, Lemeshow S. *Sampling of populations.* New York: Wiley; 1991:244–279.

6. Finkelstein RA. Vibriocidal antibody inhibition (VAI) analysis: a technique for the identification of the predominant vibriocidal antibodies in serum and for the detection and identification of *V. cholerae* antigens. *J Immunol.* 1962;89:264–271.
7. Holmgren J, Svennerholm AM. Enzyme-linked immunosorbent assays for cholera serology. *Infect Immun.* 1973;7:759–763.
8. Colton T. *Statistics in medicine.* 1st ed. Boston: Little, Brown; 1974:30–31.
9. Mantel N, Haenszel W. Statistical aspects of the analysis of data from retrospective studies of disease. *J Natl Cancer Inst.* 1959; 22(4):719–747.
10. Robins J, Greenland S, Breslow NE. A general estimator of the variance of the Mantel-Haenszel odds ratio. *Am J Epidemiol.* 1986;124:719–723.
11. Martin D, Austin H. An efficient program for computing conditional maximum likelihood estimates and exact confidence limits for common odds ratios. *Epidemiology.* 1991;2(5):359–362.
12. Breslow NE, Day NE. Volume 1: *Statistical methods in cancer research: the analysis of case-control studies.* Lyon: International Agency for Research on Cancer; 1980:142–146. (IARC publication 32).
13. Greenberg RS, Kleinbaum DG. Mathematical modeling strategies for the analysis of epidemiologic research. *Annu Rev Public Health.* 1985;6:223–245.
14. Greenland S. Modeling and variable selection in epidemiologic analysis. *Am J Public Health.* 1989;79(3):340–349.
15. Hosmer D, Lemeshow S. *Applied logistic regression.* New York: Wiley; 1989:135–175.
16. Thomas JC, Neumann CG. Choosing an appropriate measure of diarrhoea occurrence: examples from a community-based study in rural Kenya. *Int J Epidemiol.* 1992; 21(3):589–593.
17. Ties-Boerma J, Black RE, Sommerfelt AE, Rutstein SO, Bicego GT. Accuracy and completeness of mothers' recall of diarrhoea occurrence in preschool children in demographic and health surveys. *Int J Epidemiol.* 1991;20:1073–1080.
18. Kleinbaum D, Kupper LL, Morgenstern H. *Epidemiologic research: principles and quantitative methods.* Belmont: Lifetime Learning; 1982:226.
19. Blake PA, Martin SM, Gangarosa EJ. Simple case-control studies for determining the mode of transmission of cholera. In: Wood PC. *Guide to shellfish hygiene.* Geneva: World Health Organization; 1976: 73–77. (WHO offset publication 31).
20. Spira WM, Khan MU, Saeed YA, Sattar MA. Microbiological surveillance of intra-neighborhood eltor cholera transmission in rural Bangladesh. *Bull World Health Organ.* 1980;58(5):731–740.
21. Hughes JM, Boyce JM, Levine RJ, et al. Epidemiology of eltor cholera in rural Bangladesh: importance of surface water in transmission. *Bull World Health Organ.* 1982;60:395–404.
22. Blake PA, Rosenberg ML, Florencia J, Costa JB, Quintino LD, Gangarosa EJ. Cholera in Portugal, 1974; II: transmission by bottled mineral water. *Am J Epidemiol.* 1977; 105:344–348.
23. Esrey SA, Habicht JP. Epidemiologic evidence for health benefits from improved water and sanitation in developing countries. *Epidemiol Rev.* 1986;8:117–128.
24. Esrey SA, Potash JB, Roberts L, Shiff C. Effects of improved water supply and sanitation on ascariasis, diarrhoea, dracunculiasis, hookworm infection, schistosomiasis, and trachoma. *Bull World Health Organ.* 1991;69(5):609–621.
25. Ruiz-Matus C, Koopman JS, Cárdenas-Ayala VM, Herrera-Bastos E, Hinojosa-Martínez M. Enfermedad diarreica después de los sismos de 1985 en la ciudad de México. *Salud Pública Mex.* 1987;29:399–405.
26. Tauxe RV, Blake PA. Letter from Peru: epidemic cholera in Latin America. *JAMA.* 1992;267(10):1388–1390.
27. Gangarosa EJ, Tauxe RV. Epilogue: the Latin American cholera epidemic. In: Barua D, Greenough WB, eds. *Cholera.* New York: Plenum; 1992:351–358.
28. Witt VM, Reiff FM. Environmental health conditions and cholera vulnerability in Latin America and the Caribbean. *J Public Health Policy.* 1991;12(4):450–463.