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A Low-Cost Intervention for Cleaner Drinking Water in Karachi, Pakistan

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ABSTRACT

Objective: To pilot test an inexpensive, home-based water decontamination and storage system in a low-income neighborhood of Karachi.

Methods: Fifty households received a 20-L plastic water storage vessel with a high-quality spout and a regular supply of diluted hypochlorite solution. Twenty-five control households were recruited. Water samples were collected at baseline and during unannounced follow-up visits 1, 3, 6, and 10 weeks later.

Results: Baseline drinking water samples among intervention households were contaminated with a mean 9397 colony-forming units (cfu)/100 mL of thermotolerant coliforms compared with a mean 10,990 cfu/100 mL from controls. After intervention the mean concentration of thermotolerant coliforms decreased by 99.8% among the intervention households compared with an 8% reduction among controls. Two years after vessel distribution, 34 (68%) of the families were still using the vessel. Thirteen of the households had stopped using their vessel because it had broken after more than 6 months of use, a pattern most consistent with ultraviolet radiation-induced degradation of the plastic.

Conclusions: In a highly contaminated environment, a specifically designed water storage container and in-home water chlorination was acceptable and markedly improved water quality. Where plastic water vessels will be exposed to substantial sunlight, ultraviolet light stabilizers should be incorporated into the plastic.

Key Words: *developing country, drinking water, hypochlorite, Pakistan, water storage*

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An estimated 1.3 billion persons living in low-income countries do not have access to safe drinking water.[1] Diarrhea caused an estimated 2.2 million deaths in 1998, almost exclusively in these low-income countries, where safe drinking water is not readily available.[2]

In Karachi, Pakistan, a city of 10 million people, water quality is poor. Forty percent of Karachi's population lives in squatter settlements with limited water and sanitary infrastructure.[3] Population-based verbal autopsy studies in five of these squatter communities measured an under 5-year-old mortality rate of 100 deaths per 1000 live births; diarrheal diseases were the primary cause of 39% of these deaths.[4] A study among predominately middle class households throughout Karachi in 1994 found that although 67% of households attempted to purify their water, most commonly by boiling, 240 (85%) of 282 drinking water samples tested were contaminated with coliform bacteria.[5] This suggests that recontamination of water after purification may contribute to disease transmission.

The preferred method to provide quality drinking water in Karachi would be to develop and maintain an effective municipal water purification and delivery system and an effective sanitary sewerage system. However, the population growth rate of Karachi, the massive investment required to improve the poor quality and condition of the existing water distribution and sanitary system, and the financial condition and priorities of the government make a central solution to cleaner water unlikely in the short or intermediate term. Use of a plastic water

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storage vessel with home chlorination potentially offers an inexpensive, sustainable means to achieve cleaner water.[6] In a pilot study of this method in Bolivia, the percentage of households with water that met World Health Organization (WHO) microbiologic criteria for potability (<1 thermotolerant coliform per 100 mL water) improved from 21% at baseline to 93% among those receiving the vessel and a hypochlorite solution.[7] A second study in Bolivia demonstrated a 44% reduction in the prevalence of diarrhea among persons living in households who received the vessels and hypochlorite compared with controls.[8]

These results are encouraging but do not guarantee that such an intervention would work as effectively under different conditions of water contamination. In addition, Karachi residents have their own attitudes, beliefs, and understandings regarding water, which could affect the feasibility and acceptability of any intervention. Therefore, the authors conducted a pilot study to evaluate the acceptability and microbiologic effectiveness of the water storage vessel with in-home chlorination in an urban squatter settlement in Karachi.

MATERIALS AND METHODS

Setting

The study was conducted in Manzoor Colony, a typical multiethnic squatter settlement in central Karachi. A local nongovernment organization, Health Oriented Preventive Education (HOPE), which operates a community-based primary health care program in Manzoor Colony and is trusted by the community, collaborated on the project.

Intervention

The principal water storage vessel intervention was a 20-L plastic container with a lid, a narrow mouth, specifically designed to prevent entry of hands or objects into the vessel, and a high-quality tap (Catalog number 180-100A; Tolco, Inc., Toledo, OH) (Figure 1). Several bottles of several brands of household bleach available in Karachi were purchased, and a particular brand of locally manufactured bleach was selected (Javex Bleach, Colgate-Palmolive, Karachi, Pakistan), because 91% of its detectable chlorine was free chlorine and its measured chlorine concentration (4.4 mg%) was consistent among five different bottles bought from different stores. The minimum quantity of bleach needed to consistently produce a free-chlorine concentration higher than 1.0 mg/L in water samples from Manzoor Colony ultimately was determined to be 3 parts bleach to 17 parts distilled water. This diluted hypochlorite was packaged in 10-mL reusable bottles, each sufficient to achieve a free chlorination level of over 1.0 mg/L in a full 20-L water vessel.

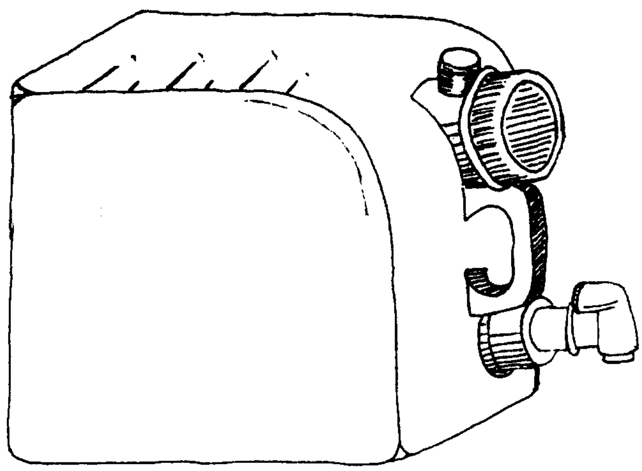

Figure 1. A 20-liter water vessel with narrow mouth and spigot.

Design

This evaluation of the water vessel was part of a larger pilot project to evaluate soap for handwashing and the vessel for drinking water. For the larger study, there were three intervention groups of 25 households each. Group 1 received the water storage vessel and hypochlorite. Group 2 received soap and instructions to use available water to wash their hands. They did not receive the water storage vessel or hypochlorite. Group 3 received the water storage vessel, hypochlorite, and soap, with instructions to drink treated water from the vessel and to use soap and water from the vessel for handwashing. The three groups were in three geographically distinct sectors of Manzoor Colony so that health education would be consistent in each neighborhood. Because the two groups that received the vessel and hypochlorite (groups 1 and 3) were similar at baseline and had similar outcomes, these groups were combined for this analysis and compared with the group without a vessel or hypochlorite (group 2).

Slide presentations, videotapes, and written pamphlets were developed to illustrate the problems resulting from water contamination and specific instructions were drafted on how to use the vessel and hypochlorite. Members of households receiving the water vessel were instructed to wait until the vessel was empty before refilling it, to add one premeasured bottle of hypochlorite to the newly filled vessel, to wait 30 minutes before drawing water from it, and to have all household members, particularly children, drink water only from the vessel. Group meetings and materials were supplemented by home meetings with community health workers who gave hands-on demonstrations and encouragement to the participating families. Community health workers returned to each household one or more times a week to encourage use, answer questions, and provide additional bottles of hypochlorite.

A structured pre-intervention survey was administered to assess socioeconomic status, water availability, and water-use habits among eligible households in the three intervention sectors. Baseline data were evaluated and final group selection was standardized so that the groups would be comparable. One difference between groups that the researchers were unable to balance was a permanent municipal water connection. Municipally supplied water typically runs 2 to 3 hours per day in these neighborhoods. When the water starts to run, residents turn on electric pumps to draw the maximum amount of water through rubber hoses connected to community water taps into their household storage tanks. In one sector, most households had their own pump with a rubber hose always connected to a tap so that when water ran they could collect it. In the other two sectors, most households shared a municipal tap with two or three neighboring households, and so used their own pump to collect water only on alternate days. It was assumed that persons with a regular water connection might have somewhat better water, thus, persons living in the sector with the largest percentage of regular water connections were assigned to receive no water vessel, that is, to a maximally conservative baseline.

A structured post-intervention survey was administered 12 weeks after distribution of the intervention, to assess users' perceptions.

In December 1999, 2 years after the pilot study was launched, the local nongovernmental organization, HOPE, was still providing dilute chlorine at no charge to households using the vessels. The record of the 47 families who used the vessel throughout the pilot study was reviewed, to evaluate long-term use and to identify any problems.

Laboratory Measurements

Stored drinking water samples were collected from all households in 120-mL sterile plastic containers with thiosulphate to neutralize chlorine at a pre-intervention baseline in October and November 1997. The vessels and hypochlorite were distributed in November and December 1997, and follow-up water samples were collected 1, 3, 6, and 10 weeks after the vessels were distributed. To evaluate the effect of adding ice, which was available in the community, to the chlorinated water, a practice that became popular as the weather turned hot late in the study, 24 additional water samples were collected in July 1998 from two different sectors of Manzoor Colony: 12 from households where locally available ice was added to a separate insulated vessel that had been filled with water originally chlorinated in the study vessel, and 12 from vessels in which 1 kg of locally purchased ice was broken up and added to chlorinated water in the study vessel.

All water samples were placed in coolers on ice and transported to the Aga Khan University Hospital Laboratory for analysis within 4 hours of collection. Free and combined chlorine levels were measured before thiosulfate was added, using the N,N-diethyl-phenylenediamine (DPD) colorimetric method (Free and Total Chlorine Kit, Hach Co., Loveland, CO).

For microbiologic evaluation, water samples were tested at three concentrations, undiluted, diluted 1:10, and diluted 1:100, with 0.01 M sterile phosphate-buffered saline. Researchers filtered 50 mL of each dilution through a sterile 0.45-m paper filter and transferred each filter to a 90-mm petri plate containing eosin-methylene blue agar. The plates were incubated at 44°C for 24 hours, then examined for thermotolerant coliform and *Escherichia coli* colony counts. Blue-purple colonies with a greenish metallic sheen were selected as possible *E. coli* and inoculated in a tube of MacConkey broth with a Durham tube and a tube of peptone water at 44°C for 24 hours. Those colonies that fermented lactose (as indicated by a change in the color of MacConkey broth) and produced gas and indole at 24 hours were classified as *E. coli*.

The countable range of colonies was 10 to 100. When the number of colonies in only one plate was within the countable range, this count was used to estimate bacterial density. When two or more plates had colonies within the countable range, bacterial density was estimated by calculating the arithmetic mean of the counts of these plates. When one or more filters had colonies too numerous to count and the more dilute filters had colonies below the countable range, the bacterial density was estimated to be at the maximum countable concentration of the most dilute filter that had colonies too numerous to count. When all the filters had colonies too numerous to count, bacterial density was estimated to be twice the upper limit of the countable range.[7]

Statistical Analysis

It was calculated that 18 households per group would be sufficient, assuming that 85% of households would have contaminated water at baseline, and that the intervention would reduce that to 30%, with 80% power at a 5% level of significance. The number was increased to 25 per arm to evaluate a greater diversity in experiences with the intervention and to allow for drop-out.

The role of chance in explaining differences between groups was evaluated by using the t-test to compare means of normally distributed variables, chi-square to compare prevalences with expected cell sizes of 5 or greater, and the Fisher's exact test to compare prevalences when the expected cell size was less than 5. Because the estimated concentrations of thermotolerant coliforms and *E. coli* varied exponentially and were not normally distributed, geometric mean concentrations were calculated and the Wilcoxon rank sum test was used to assess

Table 1. Baseline Characteristics among the Intervention versus Control Households, Manzoor Colony, Karachi 1997

Characteristic	*Intervention (n = 50)*	*Control (n = 25)*	*P-Value**
Mean number of persons residing in the household	8.0	7.2	0.22
Mean duration of residence (y)	22.3	21.4	0.79
Mean number of children <age 5 years in household	2.0	1.9	0.65
Literacy among male heads of household	78%	72%	0.60
Literacy among mothers	60%	75%	0.21
Median monthly household income range	$71–95†	$71–95†	
Municipal-water connection to household	16%	80%	<0.001
Covered concrete tank for principal water storage	86%	92%	0.45
Store water in underground concrete tanks	60%	76%	0.17
Attempt to regularly purify drinking water	48%	40%	0.51
Boil drinking water for children (at least sometimes)	51%	54%	0.81
Refrigerator ownership	48%	44%	0.74
Presence of a toilet without flush tank	96%	100%	0.55

*Based on t-test for comparison of continuous variables and the chi-squared test (or 2-sided Fisher's exact test when the expected cell size was < 5) for comparison of prevalences.
†Equivalent to 3001–4000 Pakistani Rupees.

whether differences in the distribution of concentrations between groups were likely attributable to chance. A general linear model was used to adjust for baseline differences between the intervention groups, to evaluate if the differences in geometric mean concentration of thermotolerant coliforms between groups were greater than would be expected by chance. The general linear model was extended through standard covariate structures, including unstructured, compound symmetry, and autoregressive parameters, to account for repeated measures. Epi Info version 6 (Centers of Disease Control and Prevention, Atlanta, GA) was used for data management and univariate statistical calculations, and SAS System for Windows, release 7.0 (SAS Institute Inc., Cary, NC) was used for the general linear modelling.

Ethics

The purpose of the study was explained to a responsible adult in each participating household, and verbal informed consent was obtained. The study protocol was reviewed and approved by the Human Subjects Protection Committee of Aga Khan University.

RESULTS

Forty-seven (94%) of the 50 households assigned to the intervention and 23 (92%) of 25 control households completed the study. The five households that dropped out, did so after the baseline sample collection and before the first postintervention sample at week 1.

At baseline, the group receiving the intervention and the control group were similar in household size, duration of residence, literacy, income, water purification and storage practices, and refrigerator ownership (Table 1). The only marked difference was that control group households were more likely to have a standing municipal water connection to their houses (80% vs. 16%) than households receiving the intervention.

During the study, 171 (91%) of 188 specimens collected from intervention households had detectable free chlorine (>0.1 mg/L) compared to only 1 (1%) of 92 specimens from control households. The mean free-chlorine concentration in drinking water from intervention households was 1.6 mg/L (range, 0–2.2 mg/L).

Baseline stored drinking water samples were heavily contaminated in all study households, with a geometric mean 9397 cfu/100 mL of thermotolerant coliforms in intervention households and 10,990 cfu/100 mL in control households. There was no significant difference in the level of *E. coli* contamination at baseline (Table 2). When the baseline was compared with all subsequent water specimens, there was a mean 99.8% reduction in the concentration of thermotolerant coliforms in stored drinking water samples among intervention households, in contrast to a mean 8% reduction in control households. At the four evaluations after the vessel and hypochlorite were introduced, water samples from intervention households averaged 99.98% fewer thermotolerant coliforms and 98.6% fewer *E. coli* than water samples from control households (see Table 2). Intervention households were also significantly more likely during the intervention phase to have water without detectable thermotolerant coliforms (26% vs. 0%) and *E. coli* (97% vs. 24%) compared with control households. Among the 140 stored water samples from intervention households that had detectable thermotolerant coliforms, 123 (88%) had detectable free chlorine at a median concentration of 2.2 mg/L (range, 0.1–2.2 mg/L).

In a general linear model using unstructured covariant parameters to account for repeated measures, the presence of a vessel ($P < 0.0001$), the level of total chlorine ($P < 0.001$), and the week the water sample was collected ($P < 0.001$) significantly predicted the level of contamination with thermotolerant coliforms. The presence of a standing municipal water connection and maternal literacy were not significant predictors.

Table 2. Thermotolerant Coliforms and *E. coli* in Stored Drinking-Water Samples at Baseline and after Intervention, Manzoor Colony, 1997–1998

	Baseline	*Week 1*	*Week 3*	*Week 6*	*Week 10*
Geometric mean concentration of thermotolerant coliforms					
Vessel (cfu/100 mL)	9397	41	136	6	4
No vessel (cfu/100 mL)	10990	7063	11722	11588	11376
P-value*	0.65	<0.0001	<0.0001	<0.0001	<0.0001
Specimens with no detectable thermotolerant coliforms					
Vessel n (%)	0/50 (0)	8/47 (17)	0/47 (0)	23/47 (49)	17/47 (36)
No vessel n (%)	0/25 (0)	0/23 (0)	0/23 (0)	0/23 (0)	0/23 (0)
P-value†	1.0	0.046	1.0	<0.0001	0.001
Geometric mean concentrations of *E. coli*					
Vessel (cfu/100 mL)	7	1	1	0	0
No vessel (cfu/100 mL)	14	70	61	83	130
P-value*	0.48	<0.0001	<0.0001	<0.0001	<0.0001
Specimens with no detectable *E. coli*					
Vessel n (%)	30/50 (60)	44/47 (94)	44/47 (94)	47/47 (100)	47/47 (100)
No vessel n (%)	16/25 (64)	6/23 (26)	7/23 (30)	6/23 (26)	3/23 (13)
P-value†	0.74	<0.0001	<0.0001	<0.0001	<0.0001

*Vessel group versus the no vessel group; Wilcoxon 2-sample test.
†Vessel group versus the no vessel group; chi-squared or Fisher's exact test.

Twelve weeks after the intervention began, residents in all 47 intervention households reported liking the vessel, although six (13%) suggested that the opening of the vessel should be large enough to permit easier cleaning and the introduction of ice. Forty-five households (96%) found it easier to draw water from the vessel than from the traditional clay jars commonly in homes. Thirty-seven households (79%) noted that the water tasted differently, but 44 (94%) preferred it to water in traditional clay jars. Most commonly, the vessel was filled daily (24 households, 51%), but it was filled every other day in 19 households (40%) and twice daily in 2 households (4%). Twenty-eight households (60%) reported being willing to pay 30 rupees (US$0.65) per month for hypochlorite to continue purifying their water.

By the end of the study, the Karachi weather became hot, and study participants complained that the vessel was not insulated and if ice was added it soon melted. Indeed, in only 4 (9%) of the 47 households were children still drinking water from the vessel left at room temperature. In 25 households (53%) water treated in the vessel was poured into an insulated container, and ice, generally purchased from the marketplace, was added. Three households (6%) placed the vessel in a refrigerator and 8 households (17%) put water from the vessel into smaller, sealed, plastic water bottles and placed the bottles in the refrigerator.

In 12 water samples collected from households that transferred treated water from the vessel to an insulated container and added locally available ice, the geometric mean concentration of thermotolerant organisms was 105 per 100 mL (range, 0-40,000). In the 12 water samples collected from the intervention vessels with added ice, the mean concentration of thermotolerant coliforms was 101 per 100 mL (range, 0-2500).

In December 1999, 2 years after the start of the study, 34 (72%) of the 47 families using a vessel at the end of the 12-week pilot study were still using the vessel for regular drinking water decontamination and storage. In each of the 13 households that were not using the vessel, the vessel had broken. The vessels developed a yellow color and then began developing large cracks through the molded plastic body after 8 months of use.

DISCUSSION

In a South Asian urban setting with extremely heavily contaminated source water, a safe water storage vessel and in-home chlorination reduced the amount of thermotolerant coliforms and *E. coli* in stored drinking water by more than 99%. The WHO recommends that drinking water contain no detectable *E. coli* and no detectable thermotolerant coliform bacteria per 100 ml.[9] Only 26% of treated samples met these criteria. However, since the risk for and severity of illness for most enteric pathogens depend on the dose of exposure,[10-12] substantial reductions in the level of contamination in drinking water would be expected to improve health. The actual effect that this cleaner, but not 100% potable, drinking water has on health, especially among children under age 5 years, needs to be assessed in further studies.

Most treated drinking water samples in which persistent coliform contamination was detected were not underchlorinated. Although we did not measure for the presence of organic compounds or other chemical characteristics of the water, the most likely explanation of the persistence of viable organisms in the setting of adequate levels of chlorination is that residual organic or other particulate matter in the water provided a microenvironment where bacteria were sheltered from the effect of chlorine.[13] Filtering the water before chlorination would likely have improved effectiveness, but would add complexity and cost to the system.

The frequent, but delayed breakage of the vessel with long cracks in the plastic and discoloration after several months of use is consistent with a pattern of damage from ultraviolet light.[14] The vessels were designed to store compounds inside buildings, and so did not have ultraviolet light stabilizers added in the plastic to resist breakdown by ultraviolet light. In many of the homes in Manzoor Colony, the vessels were kept in an open courtyard. Ultraviolet light stabilizers, expected to add $0.06 to the price of each vessel, (Personal Communication Polyoak Visconti, South Africa) are essential if plastic water storage vessels are to last long enough so that they prove popular and affordable.[15]

Assuming the problem with breakage is addressed, the vessel and in-home chlorination system is affordable. Among the urban squatter residents of Karachi, the price of this vessel, if manufactured locally, would be comparable to the cost of other water storage containers (US$3-4) available in the market. A 1-month supply of bleach would cost US$0.40 if bought in a concentrated bottle, and $0.65 if purchased in individual bottles dosed for a single treatment. The vessel was popular. All families given a vessel continued to use it, as long as it remained unbroken, even 2 years after the project was launched. The majority of users expressed a willingness to purchase hypochlorite solution, though this was not tested. In this pilot study, the vessel and in-home chlorination were introduced within a dynamic community-based, primary health care program, and supported by an intensive motivational and educational campaign. For this approach to have a broader societal impact, methods for motivating people to purchase, accept, and use this technology properly without the intensive house-to-house support and supervision that was used in the pilot study are needed. Mass-marketing efforts have been used successfully in Bolivia.[16]

Hypochlorite solution was distributed to families in small reusable plastic bottles, with each bottle containing sufficient hypochlorite that when added to the 20-L vessel it reliably produced residual free chlorine without unpalatable overchlorination. These bottles were well accepted and consistently used, though they required an ongoing commitment of time from the community to collect and refill them with appropriately diluted hypochlorite solution. Since supplies were distributed weekly, degradation of hypochlorite was not a problem.[17] If a program were to provide a larger quantity of dilute hypochlorite in the home, storing it in a cool place in sealed dark containers can help to maintain free available chlorine levels for over 1 month.[18,19]

Even in this low-income community, residents prefer and are accustomed to drinking cold water. Ice purchased in the marketplace is made from heavily contaminated municipal water. Therefore, adding ice to treated stored water introduces an ongoing source of contamination. However, samples taken after ice was added had a level of contamination similar to that of other treated water in the study. Thus, further efforts to adapt this approach to Karachi and work toward local production and more widespread use of a vessel and in-home chlorination system need not proscribe the popular habit of using ice in hot weather.

There is some evidence that persons in developed countries whose drinking water is chlorinated are at a mildly elevated risk for some malignancies, especially bladder cancer, compared with persons whose water is not treated with chlorine.[19] These risks are thought to be mediated through chlorination of organic compounds which would be expected to occur in higher concentration when chlorine is added to heavily contaminated water like that in Karachi, compared with water treated at modern water treatment plants to reduce the organic load. However, untreated water with heavy microbial contamination presents a much higher risk of death from diarrheal disease, especially among children under 5 years of age in these communities, than the possible slightly increased risk of malignancy with long-term exposure to chlorination byproducts.

Households in the control group had a more regular connection to the municipal water supply than households receiving the intervention. In the general linear model, however, this difference did not explain the difference in water quality between the vessel and the control group. The intervention and control groups had similar water quality at baseline, and postintervention samples from the intervention households were markedly cleaner than both baseline samples and samples from control households.

For the analysis of drinking water contamination, households that received the water vessel and hypochlorite alone were combined with households that received the water vessel and hypochlorite and soap. These vessel intervention households were compared with households that received only soap. If receiving soap affected drinking water quality, then this comparison would not measure the independent effect of the water vessel and hypochlorite in improving water quality. However, there was no difference in water quality between households that received the water vessel, hypochlorite, and soap and households that received the water vessel alone. Moreover, households that received soap alone still had heavily contaminated drinking water. Thus, it is reasonable to ascribe the improvement in water quality to the water vessel and hypochlorite.

In mega-cities in developing countries, where population growth rates exceed the capacity of governments to provide microbiologically safe drinking water, use of the safe water storage vessel and in-home chlorination intervention offers a potentially life-saving intervention to city residents.

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