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DELAYED EFFECTIVENESS OF HOME-BASED INTERVENTIONS IN REDUCING CHILDHOOD DIARRHEA, KARACHI, PAKISTAN

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Abstract. We introduced home drinking water disinfection and handwashing with soap in Karachi squatter settlements to evaluate their effect on diarrhea. In April 2000, 150 households received soap, 76 received dilute bleach and a water storage vessel, and 76 were enrolled as controls. In 2000, among households wealthy enough to own a refrigerator, children in households that received bleach and a vessel had a 73% lower incidence of diarrhea than controls; those that received soap had a 56% lower incidence. There was no reduction in diarrhea in intervention households without a refrigerator. In 2001, households that received bleach and a vessel had a 71% lower incidence of diarrhea and children in households that received soap had a 35% lower incidence than controls. In 2001, the interventions were equally effective in households that had a refrigerator and those that did not. Both of these home-based interventions were ultimately effective in preventing diarrhea, but only households of slightly higher socioeconomic status changed their behavior quickly enough to benefit during the first summer.

INTRODUCTION

Diarrhea is a leading cause of childhood death globally. The World Health Organization estimates that two million children died of diarrheal disease in 2001.[1] These deaths were concentrated among low income families living in low income countries.[2]

Two home-based interventions, disinfecting drinking water with bleach and washing hands with soap, have been proven in multiple small-scale evaluations to decrease the incidence of diarrhea.[3–6] Water disinfectant and soap are inexpensive commodities that the private sector can manufacture and sell to at-risk families, thereby furthering sustainable interventions to prevent diarrhea. However, motivating at-risk families to change their behavior and adopt in-home water treatment and handwashing as routine practice is a substantial task that typically requires more resources than businesses can recover through product sales, especially in those communities where diarrheal mortality is highest. Understanding the pace and process through which families adopt home drinking water treatment and handwashing may provide insight on how to promote behavior change more efficiently.

In Karachi, Pakistan, 40% of the population lives in squatter settlements where water and sanitary infrastructure is limited.[7] In these communities, infant mortality is high, and 40% of all deaths among children less than five years of age are due to diarrhea.[8] In prior studies, households in these communities that added dilute bleach to their highly contaminated drinking water and stored it in vessels that prevented re-contamination had markedly less contaminated water than households with standard water handling practices.[9] Even households that transferred bleach-treated water to locally purchased insulated vessels and added highly contaminated ice, had markedly cleaner water. Families that received soap and were encouraged to wash their hands had lower concentrations of thermotolerant coliforms detected on their hands at unannounced follow-up visits compared with families that did not receive soap and handwashing instructions.[10]

These promising microbiologic results suggested that these two household level interventions would yield health benefits to families that adopt them. To test this hypothesis, we introduced home drinking water treatment and handwashing with soap in separate neighborhoods in Karachi squatter settlements. We evaluated the impact these interventions had on the incidence of diarrhea and the time required to change household behavior to make these interventions effective.

MATERIALS AND METHODS

Setting. This study was conducted in adjoining multi-ethnic squatter settlements in central Karachi, Manzoor Colony and Mujahid Colony, in collaboration with Health Oriented Preventive Education (HOPE), a non-governmental organization that provides community-based health and developmental assistance in these communities. HOPE field workers were trained women and men who have completed at least eight years of education, represented a variety of ethnic and linguistic groups, and lived either in the study communities or nearby communities.

Only some of the households in these communities had access to the municipal water supply system. The municipal system supplied water intermittently, typically for 1–2 hours per day. At those times, residents turned on electric pumps to draw the maximum amount of water through rubber hoses connected to community water taps into their household storage tanks. Some households had their own pump with a rubber hose always connected to a tap so that they could collect water whenever it was available. More commonly, households shared a municipal tap with neighboring households, and so used their own pump to collect water only on alternate days. Households with no municipal water connection typically purchased water from commercial water sellers who sold water by the tanker truck or in smaller volumes.

Bar soap was commonly sold in the small stores throughout these communities. Handwashing, typically with water alone, is part of regular ritual preparation for prayer, though thorough washing of hands with soap is less common. Children in these communities routinely bathe daily using a bucket bath. They remove their clothing, take one or two cups of water, pour it over their head and skin, lather with soap, and use another cup or two of water to rinse off.

This study was primarily designed to evaluate whether bathing with antibacterial soap would reduce the incidence of impetigo compared with bathing with plain soap. Other elements were added to the study to evaluate the role of water treatment and handwashing on the rate of diarrhea. The impetigo results have been reported.[11] This analysis focuses on diarrhea outcomes.

Interventions. *Bleach.* Field workers diluted three parts of locally manufactured bleach (4.4 mg% sodium hypochlorite) with 17 parts distilled water, and packaged the dilute hypochlorite into 10-mL reusable plastic bottles. One plastic bottle of dilute bleach added to 20 liters of locally available water typically produced a free chlorine residual between 0.5 mg/L and 2.0 mg/L.

Imported vessel. The imported water vessel was a 20-liter plastic container with a narrow mouth (8 cm), lid, and tap that allowed easy drawing of stored water while protecting it from contaminated hands.

Local vessel. The locally manufactured water vessel was a 20-liter insulated plastic container with a wider mouth (15 cm), lid, and a tap. During summer months, participants commonly added ice to the water stored in the insulated vessel.

Soap. Three different variations of Safeguard® (Procter & Gamble Company, Cincinnati, OH) bar soap were used during the study, but since they would be equally effective in preventing diarrhea, all households receiving soap were analyzed together. At the initiation of the study, half of the families in the soap group received generically packaged, unbranded soap that contained 1.2% triclocarban as an antibacterial agent; this soap was chemically identical to the commercial Safeguard® product. The other half of the families in the soap group initially received generically packaged soap that was identical to the first soap, except that it contained no triclocarban. Triclocarban is a bacteriostatic compound that inhibits the growth of some gram-positive bacteria, and so was relevant for comparing impetigo rates, but triclocarban is not effective against gram-negative bacteria, viruses, or parasites that cause infectious diarrhea.[12,13] When supplies of the generically packaged soap were exhausted in the winter of 2001, and the impetigo evaluation was complete, commercially packaged Safeguard® was substituted and the diarrhea evaluation was continued.

Behavior change. Field workers arranged neighborhood meetings and used slide shows, videotapes, and pamphlets to illustrate health problems resulting from hand and water contamination and to provide specific instructions on how to use the study intervention. Field workers visited each participating house at least weekly. In visits to intervention households, they promoted discussion and answered questions about the intervention, re-supplied families with bleach or soap, and encouraged regular use of the interventions.

Study groups in 2000. The study began in May 2000 in three different neighborhoods. Participants in one neighborhood received bleach and the imported vessel. Study workers encouraged this group to regularly treat their drinking water, but did not encourage or instruct them to wash their hands.

Participants in the second neighborhood received soap. They were instructed to continue their regular routine of bathing and hand washing, but to substitute their usual soap with the study soap. No specific instructions on how or when to wash hands were provided.

Households in the third neighborhood, the standard habits and practices control group, received a regular supply of children's books, notebooks, pens, and pencils to help with their children's primary education. They received no products or specific instructions expected to affect their risk of diarrhea.

Study groups in 2001. The intervention continued longer than originally envisioned. Families who moved out of the study area or dropped out of the study for other reasons were replaced with neighbors who consented to participate. To increase statistical power, additional control households were recruited.

Beginning in December 2000, the behavior change messages to households in the soap group were revised to encourage handwashing to prevent diarrhea. Specifically, household residents were encouraged to wash their hands thoroughly for at least 45 seconds to remove all visible dirt. They were also encouraged to wash hands at key times: before cooking, before eating, before feeding a child, after defecation, and after children came inside from playing outside.

A fourth intervention group was added in a fourth neighborhood in June 2001. This group received dilute bleach and a locally manufactured insulated vessel. Households typically added ice to the insulated vessel to keep water cold. Study workers visited weekly, encouraged regular treatment of drinking water, and re-supplied the households with dilute bleach.

Eligibility. Eligible households were located in Manzoor Colony or Mujahid Colony, provided informed consent, included at least one child less than five years of age and two children less than 15 years of age, had sufficient water supply for the children to bathe daily, and planned to continue to reside in their homes for at least the ensuing four months. Only children less than 15 years of age were followed in the study.

Measurements. Trained field workers conducted a pre-intervention baseline survey to characterize hand washing and bathing practices, soap consumption, and drinking water storage and purification practices. Field workers then visited participating households each week to collect information on disease occurrence and, in intervention households, to encourage regular and appropriate use of the intervention.

Diarrhea was defined as three or more loose stools in a 24-hour period. Each week was classified as either a week with or without diarrhea. A child was considered at risk for a new episode of diarrhea if they had reported no diarrhea in the preceding week.

Laboratory analysis. Baseline drinking water samples were collected from the bleach plus imported vessel and the control households at baseline and evaluated for the presence of thermotolerant coliforms and *Escherichia coli* using standard membrane filtration methods.[9]

Sample size. We calculated a sample size of 75 households per group for six months of observation assuming seven episodes of diarrhea per 100 child-weeks in children less than five years of age in the control group, a 25% reduction in diarrhea incidence for children in intervention households, two children less than five years of age per household, a 20% loss of statistical power from household clustering and repeated weekly measurements, 95% confidence, and 80% power.

Statistical analysis. Because the interventions differed at different times and because diarrhea incidence varies by season in Karachi, the data were analyzed during two similar

time periods May 1–October 31, 2000 and June 1–October 31, 2001. Analysis for 2001 began one month later because the intervention did not begin in the insulated vessel group until June 2001.

Diarrhea incidence was calculated as the number of new episodes of diarrhea divided by the number of child weeks at risk. Rates were compared between intervention groups versus control and by household and child characteristics using rate ratios.

The data were modeled using generalized estimating equations to control for confounding and to account for the dependence of the repeated measures of the same individual.[14] The dependent variable was the presence or absence of diarrhea in a child week at risk for a new episode of diarrhea. Model building began with the intervention group predicting diarrhea, and then other characteristics of the study population associated with diarrhea in the bivariate analysis (rate ratio <0.8 or >1.2) were added to the model. Only those characteristics that both significantly improved fit and were independently associated with the outcome were retained in the model. A strong interaction was noted with refrigerator ownership in the 2000 data, so separate models were developed for households with and without refrigerators. For the 2001 data, a nested correlation structure was imposed where the correlation of repeated observations of an individual were treated as a subset of the correlation structure of the household. For the 2000 data, the added complexity of the nested correlation led to even the simplest models failing to converge. Thus, we used an exchange correlation structure of the repeated measures of the individual child. We used SAS software for data analysis (SAS System for Windows, Version 8; SAS Institute, Inc., Cary, NC).

Ethics. Community leaders and heads of households provided informed consent. The study protocol was reviewed and approved by the Ethics Review Committee of the Aga Khan University and an Institutional Review Board of the Centers for Disease Control and Prevention.

RESULTS

Baseline. The three study groups were broadly similar in April 2000 (Table 1). However, households that received bleach and an imported vessel were much less likely to have purchased hand soap in the preceding two weeks, and to have used municipally supplied water as their principle source of drinking water compared with households that received soap or were in the control group (Table 1). The level of bacterial contamination of drinking water was similar between households in the control and bleach group. Households in the control group were less likely to have a flush toilet.

Most of the participating households in June 2001 were the same households from the summer of 2000 that had participated continuously. Of the 148 households that received soap in June 2001, 126 (85%) were households that had received soap since April 2000. Of the 80 households that received bleach and an imported vessel in June 2001, 51 (64%) were households that had enrolled in April 2000 and of the 130 control households in June 2001, 72 (55%) had been control households since April 2000.

In June 2001, the groups were again broadly similar, but with differences similar to those noted in April 2000 (Table 1). Households that received bleach and an imported vessel were less likely to have purchased hand soap in the preceding two weeks compared with the other groups. Households in both of the bleach groups were less likely to receive their drinking water from the municipal supply than households in the soap or control group.

2000 rates. Between May and November 2000, field workers collected the mothers' report on diarrhea for 27,348 child weeks of observation; 26,545 child weeks were at risk for a new episode of diarrhea. There were 352 new episodes of diarrhea (1.32 episodes/100 child weeks). Younger children had more episodes of diarrhea than older children (7.5 episodes/100 child weeks among children <1 year of age, 3.8 episodes/100 child weeks among children 1 to <2 years of age,

TABLE 1
Baseline household characteristics by intervention group, Karachi, Pakistan

Household characteristic	2000			2001			
	Soap (n = 150)	Bleach and imported vessel (n = 76)	Control (n = 76)	Soap (n = 148)	Bleach and imported vessel (n = 80)	Bleach and local vessel (n = 75)	Control (n = 130)
Mean							
Persons per household	7.9	7.7	8.0	8.5	8.0	9.3	7.9
Age of children (years)	6.3	6.6	6.0	7.4	7.4	5.7	7.1
Thermotolerant coliforms per 100 mL of drinking water		2.0×10^4	1.6×10^4				
% of							
Study children <2 years old	12	12	13	6	8	18	9
Households owning a refrigerator	37	46	38	41	51	47	33
Maternal literacy	42	47	46	36	54	61	47
Paternal literacy	72	86	68	72	84	67	70
Household income >70 US$/month	25	40	33	23	40	27	23
Households that bought soap in the 2 weeks before the study	64	9	53	62	15	37	47
Principle source of household water*							
Municipal supply within the house	11	1	29	12	2	1	16
Municipal supply at a community tap	26	0	39	26	0	11	41
Tanker truck	55	99	32	52	98	86	43
Other	9	0	0	10	0	1	0
Report treating drinking water	25	50	39	27	53	52	33
Flush toilet in the home	37	29	1	35	25	9	4
0 thermotolerant coliforms per 100 mL of stored drinking water		4	0				
0 *Escherichia coli* per 100 mL of stored drinking water		62	61				

* Percentages do not sum to 100% because of rounding.

1.5 episodes/100 child weeks among children 2–<5 years of age, and 0.5 episodes/100 child weeks among children 5–15 years of age).

Compared with children living in control households, children living in households that received bleach and an imported vessel had a 29% lower incidence of diarrhea, and children living in households that received soap had a 13% lower incidence (Table 2).

In 2000, the difference in diarrhea incidence between the intervention groups and control occurred almost entirely within households wealthy enough to have a refrigerator. Compared with children living in control households that had a refrigerator, children living in households with a refrigerator that received bleach and an imported vessel had a 73% lower incidence of diarrhea, while children living in households with a refrigerator that received soap had 56% lower incidence (Table 2). During 2000, intervention households without a refrigerator had no reduction in diarrheal incidence compared with control households without a refrigerator (Table 2). During 2000, households in the control group without a refrigerator had a somewhat lower rate of diarrhea (1.34 episodes/100 person weeks) than control households with a refrigerator (1.83 episodes/100 person weeks, Table 2). The incidence of diarrhea among refrigerator owners who received soap or water treatment was markedly lower than either the refrigerator owners or non-owners in the control group (Table 2).

Compared with households that did not have a refrigerator, households that had a refrigerator were more likely to be headed by a literate father (85% versus 69%), to have a literate mother (52% versus 36%), and to report a household income >70 US$/month (46% versus 20%).

2001 rates. Between June and November 2001, field workers collected the mothers' report on diarrhea for 34,066 child weeks of observation; 32,533 child weeks were at risk for a new episode of diarrhea. There were 446 new episodes of diarrhea (1.37 episodes/100 child weeks). Younger children had higher rates of diarrhea than older children (4.1 episodes/100 child weeks among children <1 year of age, 4.2 episodes/100 child weeks among children 1–<2 years of age, 2.2 episodes/100 child weeks among children 2–<5 years of age, and 0.7 episodes/100 child weeks among children 5–15 years of age).

Compared with children living in control households, children living in households that received bleach and an imported vessel had a 71% lower incidence of diarrhea, children living in households that received soap and instructions on critical times to wash hands had a 35% lower incidence, and children living in households that received bleach and a local vessel had a 20% lower incidence (Table 2). In 2001, interventions were equally effective in reducing diarrhea whether households had a refrigerator (Table 2). In 2001, the incidence of diarrhea among households with a refrigerator in the control group (1.82 episodes/100 person weeks) was similar to the incidence of diarrhea among households without a refrigerator (1.99 episodes/100 person weeks).

Time effects. In September and October of 2000, the point estimate of the incidence of diarrhea was substantially lower in intervention households with a refrigerator than among control households with a refrigerator (Figure 1). In September and October of 2001, the point estimate of the incidence of diarrhea was lower in intervention households compared with control households both among households with and without refrigerators (Figures 1 and 2).

In 2001, children living in households that received bleach and the imported water vessel and had enrolled in the study in April 2000 reported lower diarrhea incidence (0.41/100 child weeks) than children living in households that received the same intervention but had enrolled later (0.87 episodes/100 child weeks). Reported diarrhea in 2001 was similar among households that originally received soap in the summer of 2000 (1.25 episodes/100 child weeks) and those that received soap later (1.32 episodes/100 child weeks).

Multivariate analysis. Generalized estimating equation models of these data, which accounted for repeated measures and significant covariates, including age, and where appropriate, income, confirmed the patterns seen in bivariate and stratified analysis. In 2000, compared with children living in control households that had a refrigerator, children living in households that received bleach plus an imported vessel and had a refrigerator had a 59% lower adjusted rate of diarrhea (adjusted risk ratio [ARR] = 0.41, $P = 0.006$). Children in

TABLE 2
Diarrhea incidence by intervention group, year, and refrigerator ownership Karachi, Pakistan

	May–Nov 2000			June–Nov 2001			
	Soap	Imported vessel and bleach	Control	Soap	Imported vessel and bleach	Local vessel and bleach	Control
All participants							
Child weeks of observation*	13,445	6,032	7,068	11,014	6,105	6,387	9,027
No. of new episodes of diarrhea (episodes/100 child weeks)	179 (1.33)	65 (1.08)	108 (1.53)	139 (1.26)	34 (0.56)	99 (1.55)	174 (1.93)
Difference in diarrhea incidence versus control (%)	–13	–29	Ref†	–35	–71	–20	Ref†
Refrigerator in household							
Child weeks of observation*	5,229	2,818	2,681	4,552	3,224	3,002	3,301
No. of new episodes of diarrhea (episodes/100 child weeks)	42 (0.80)	19 (0.67)	49 (1.83)	57 (1.25)	16 (0.50)	44 (1.47)	60 (1.82)
Difference in diarrhea incidence versus control (%)	–56	–73	Ref†	–31	–73	–19	Ref†
No refrigerator in household							
Child weeks of observation*	8,216	3,214	4,387	6,462	2,881	3,237	5,726
No. of new episodes of diarrhea (episodes/100 child weeks)	137 (1.67)	46 (1.43)	59 (1.34)	82 (1.27)	18 (0.62)	55 (1.70)	114 (1.99)
Difference in diarrhea incidence versus control (%)	+24	+6	Ref†	–36	–69	–15	Ref†

* Restricted to child weeks at risk of a new episode of diarrhea.
† Reference group.

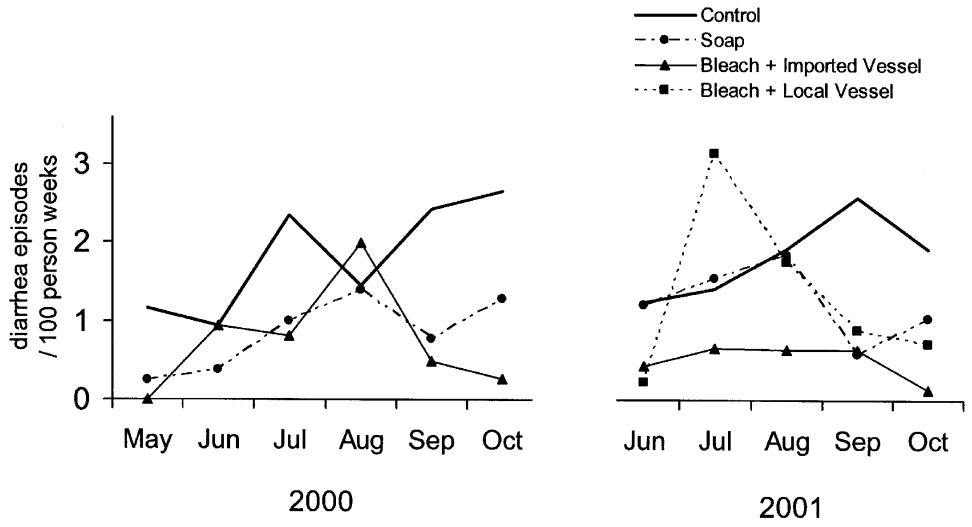

FIGURE 1. Diarrhea incidence by intervention group and month among households with refrigerators.

households that had a refrigerator and received soap had 51% lower adjusted rate of diarrhea than controls (ARR = 0.49, $P = 0.003$) (Table 3). Among households that did not have a refrigerator, intervention households had no significant difference in diarrhea incidence (ARR = 1.1) compared with control households (Table 3).

In 2001, all of the children in intervention households had an adjusted risk of diarrhea significantly less than children in control households. Households receiving soap and handwashing instructions had 29% lower risk (ARR = 0.71, $P = 0.002$); households receiving bleach plus an imported vessel had a 70% lower risk (ARR = 0.30, $P < 0.001$), and households receiving bleach plus a local vessel had a 40% lower risk (ARR = 0.60, $P < 0.001$). In 2001, having a refrigerator, either by itself or as an interaction with the intervention group, did not significantly improve the fit of the model and was not independently associated with diarrhea.

DISCUSSION

Preventing diarrhea in settings where it is a leading cause of death requires both effective technology and effective methods to change behavior. This study suggests when simple intervention technologies are rapidly introduced, achieving the behavior change necessary to take full advantage of these technologies requires considerable time. After introduction of each of the interventions, there was a delay of three to four months before diarrhea incidence among children in intervention households was lower than that of children in control households.

The field workers were not surprised by this delayed effectiveness, and described three phases of communication to encourage behavior change. First, field workers explained to participants what the intervention was and why it made sense for community residents to use it. After a few weeks, field workers focused on the specifics of how to properly use the intervention. After a few more weeks, when users both understood the value of the intervention and were comfortable with using it, the focus of the communication turned to motivating every day, every time use. This last phase of habit formation required the most time, but these data suggest that with continued visits and continued encouragement these habits were adopted.

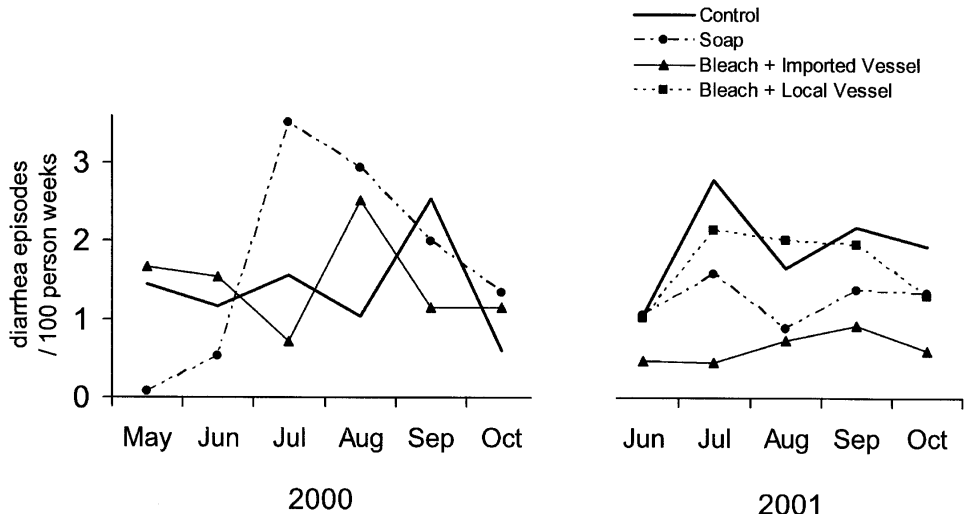

FIGURE 2. Diarrhea incidence by intervention group and month among households without refrigerators.

TABLE 3
Multivariate analysis of the relationship between intervention groups and diarrhea episodes, Karachi, 2000 and 2001

Group	May–Nov 2000 Refrigerator in household			May–Nov 2000 No refrigerator in household			June–Nov 2001 All households		
	Adjusted risk ratio*	95% confidence interval	P†	Adjusted risk ratio‡	95% confidence interval	P†	Adjusted risk ratio*	95% confidence interval	P†
Soap	0.49	0.30, 0.79	0.003	1.1	0.72, 1.6	0.71	0.71	0.45, 0.96	0.002
Bleach plus regular vessel	0.41	0.22, 0.77	0.006	1.1	0.64, 1.8	0.77	0.30	0.16, 0.52	<0.001
Bleach plus insulated vessel							0.60	0.37, 0.84	<0.001
Control	Ref§	Ref§	Ref§	Ref§	Ref§	Ref§	Ref§	Ref§	Ref§

* Of episode of diarrhea versus control adjusted through a generalized estimated equation model for age and repeated measures.
† Difference versus control.
‡ Of episode of diarrhea versus control adjusted through a generalized estimated equation model for age, income, and repeated measures.
§ Reference group.

These results further suggest that some households adopt new behaviors sooner than others. In these squatter settlements, households that had a refrigerator benefited in the first summer from either bleach plus the imported vessel or soap, while households without a refrigerator that received the same interventions had no difference in diarrhea incidence from controls. Refrigerator ownership is an objective marker of socioeconomic status, of success in a difficult environment, that is less prone to misclassification than reported level of literacy or income. A similar pattern of differential effectiveness with the interventions was seen when data were stratified by father's literacy or monthly household income >70US$. However, the effect was most pronounced with refrigerator ownership, and once this was accounted for, reported literacy and income had no further substantive effect. Refrigerator owners had a little more wealth than nonowners, but their drinking water, and their children's environment remained heavily contaminated with sewage. Indeed, in the control group, children of refrigerator owners did not have less diarrhea then children in households without a refrigerator.

Refrigerators do make it easier to keep chlorine-treated water cool without adding highly contaminated ice purchased in the marketplace, and this may have enhanced the effectiveness of home water treatment. However, refrigerator owners also benefited from receiving soap, even before receiving specific instructions on key times to wash hands for diarrhea prevention. This further supports the notion that refrigerator ownership identified a broader household characteristic associated with more rapid, effective use of interventions.

Rogers describes the process by which innovation spreads through a society.[15] First, innovators and earlier adopters, who typically have higher socioeconomic status, quickly try the innovation. In these Karachi squatter settlements, refrigerator owners behaved like early adopters, that is, their early reduction in diarrhea incidence suggests they quickly adopted the necessary behavior change to benefit from the interventions. If early adopters find an innovation useful, they communicate the value of the innovation to other persons in their community. As more and more people try the innovation and find it useful, there are more change agents in the community who can demonstrate the innovation's effectiveness and encourage others to adopt. The late majority and the laggards are the latest groups and the most difficult to change. They typically have lower socioeconomic status, and learn about new ideas from peers via interpersonal communication. Handwashing and home water treatment followed this typical diffusion of innovation pattern even when the innovations were provided at no cost. One of the core challenges for public health is that households that are slowest to adopt change are typically those with the most precarious health, the group that would most benefit from intervention. In this population, the late majority and laggards were ultimately reached with both handwashing and home water treatment and safe storage, but not until several months of weekly visits, and well after the refrigerator owning early adopters had changed their behavior and realized the health benefit.

This study provides further evidence that in communities where diarrhea is a leading cause of death, treating drinking water with chlorine and storing it safely reduces the incidence of diarrhea. Indeed, the 73% reduction in diarrhea illness versus control noted in the second summer is a larger reduction than reported in all but one of the prior evaluations of home water treatment with bleach.[3,4,15,16] The most likely explanation for this large reduction in diarrhea is that an effective behavior change intervention was given sufficient time to reach all of the people in targeted households. Indeed, if the evaluation had stopped after the first summer, the measured effectiveness in preventing diarrhea (41%) would appear similar to evaluations in other settings. Of course, in these squatter settlements where drinking water is heavily contaminated with sewage, an unusually high proportion of diarrheal illness may be transmitted through contaminated water. Furthermore, the 95% confidence interval is wide, with a lower limit corresponding to a 48% reduction in diarrhea, which is still quite effective but closer to estimates from other settings.

This study also adds to the considerable body of evidence that in settings of high diarrhea incidence hand washing with soap reduces diarrhea.[6] It suggests that for persons of lower socioeconomic status, providing soap is not enough, and that specific instruction and encouragement to wash hands at key times is crucial to achieving behavior change that leads to measurable health benefits.

In the highly contaminated environment of the Karachi squatter settlements, there are multiple opportunities for diarrheal pathogens to enter the alimentary tract of susceptible children. This study suggests that either reducing the pathogen load on hands or reducing the pathogen load in drinking water will reduce diarrheal disease. This study was not designed for and does not have the power to assess whether home water treatment or handwashing with soap is more effective in preventing diarrhea. Future research that combines these two interventions and evaluates how much of their benefit is additive would be helpful.

There are important limitations to this analysis. First, the intervention groups represented three geographically separated neighborhoods. There were differences in these neighborhoods, most importantly, differences in their water supply, differences in the presence of flush toilets, and differences in soap buying habits at baseline. It is possible that either these or some other unmeasured difference in the communities contributed importantly to the difference in diarrhea incidence noted in the different groups. However, the limited available water quality measurements in the control and bleach plus imported vessel group in the summer of 2000, as well as prior research,[9] suggests widespread sewage contamination of available drinking water in these communities. Moreover, the multivariate analysis confirmed the relationship between intervention group and diarrhea; factors known to be associated with diarrhea were either included in or did not contribute significantly to the model.

A second limitation is that the study did not collect data on the frequency of appropriate intervention use. Our interpretation of the data assumed that the reduction in disease resulted from appropriate use of the intervention. While this interpretation would be strengthened by supporting data on levels of chlorine in drinking water and microbiologic measures of hand cleanliness, it is difficult to imagine a hypothesis other than more rapid uptake of the interventions in households with refrigerators to explain that 1) in the control group households with refrigerators had a similar rate of diarrhea as households without refrigerators; 2) in the intervention groups households with refrigerators rapidly experienced reduced rates of diarrhea compared with controls and compared with households without refrigerators in the intervention groups; and 3) that with time in the intervention group the rate of diarrhea was the same in households with and without a refrigerator.

A third limitation is that this study was not originally undertaken to evaluate the hypotheses that there would be a time delay in the effectiveness of interventions, or that some sub-group of intervention households would respond sooner than other households. Indeed, the study was not originally designed to last beyond six months or to add an additional intervention group or enroll additional control households. Thus, these conclusions while consistent across different analytic approaches and consistent with the broader scholarship on diffusion of innovations, should be considered preliminary, and should be assessed in other settings.

In these Karachi squatter settlements where diarrhea is a leading cause of death, this study demonstrated that with an effective strategy for changing behavior, two approaches prevented diarrheal illness: in-home drinking water treatment and safe storage, and handwashing. Weekly interpersonal visits for more than a year were effective at changing habits in nearly all of the study households. Although the intervention elements are themselves low cost, this approach to behavior change is prohibitively expensive to scale up to the billions of persons who live in high risk settings. Thus, the next challenge is to optimize the methods for behavior change. These data suggest that a focused effort on at-risk households of marginally higher socioeconomic status might have a more rapid and cost-effective health impact. This is a group that private business may be able to reach with targeted marketing programs that recover their costs. Diffusion of innovation theory suggests that innovations with their associated behavior changes would then be expected to diffuse through communities, though it might be helped by explicit strategies that target community opinion leaders.[15] The development and evaluation of this approach holds the potential to extend the benefits of simple interventions to hundred of millions of at-risk households.

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Disclaimer: Inclusion of trade names is for identification only and does not imply endorsement by the Centers for Disease Control and Prevention or the Department of Health and Human Services.

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