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Local Drinking Water Filters Reduce Diarrheal Disease in Cambodia: A Randomized, Controlled Trial of the Ceramic Water Purifier

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Abstract. A randomized, controlled intervention trial of two household-scale drinking water filters was conducted in a rural village in Cambodia. After collecting four weeks of baseline data on household water quality, diarrheal disease, and other data related to water use and handling practices, households were randomly assigned to one of three groups of 60 households: those receiving a ceramic water purifier (CWP), those receiving a second filter employing an iron-rich ceramic (CWP-Fe), and a control group receiving no intervention. Households were followed for 18 weeks post-baseline with biweekly follow-up. Households using either filter reported significantly less diarrheal disease during the study compared with a control group of households without filters as indicated by longitudinal prevalence ratios CWP: 0.51 (95% confidence interval [CI]: 0.41–0.63); CWP-Fe: 0.58 (95% CI: 0.47–0.71), an effect that was observed in all age groups and both sexes after controlling for clustering within households and within individuals over time.

INTRODUCTION

An estimated 1.8 million people die every year from diarrheal diseases.[1] The majority of deaths are associated with diarrhea among children < 5 years of age in developing countries, who are more susceptible to malnutrition, dehydration, and other secondary effects associated with these infections. Most diarrheal illness is associated with unsafe water and inadequate sanitation and hygiene.[2–4]

Over 1.1 billion people worldwide lack access to improved drinking water sources, and many more lack access to safe water as defined by the World Health Organization (WHO) risk-based Guidelines for Drinking-water Quality.[5] Because conventional piped water systems using effective treatment to deliver safe water to households may be decades away in much of the developing world, many of the poorest people must collect water outside the home and manage (treat and/or store) it themselves at the household level.[6] This gap in service is a serious public health issue and has been addressed in the Millennium Development Goals, which aim to halve, by 2015, the proportion of people without access to safe water in 2000.[7]

For the estimated 66% of Cambodians without access to improved drinking water sources[8] and the likely much greater percentage without consistent access to microbiologic safe water, point-of-use (POU) water treatment may play a critical role in protecting users from waterborne disease. Surface water in Cambodia is plentiful but often of very poor quality, due in part to inadequate or nonexistent sanitation in rural and urban areas[8] and the lack of community water treatment. As efforts are made to direct Cambodians away from groundwaters contaminated with arsenic,[9,10] there are increased risks of diarrhea and other waterborne infectious diseases resulting from the use of more fecally contaminated surface waters, impacted shallow ground waters, and rain water that may be susceptible to contamination in storage.

Recent meta-analyses of intervention trials have suggested that improvements in household water quality are associated with a substantial reduction in diarrheal disease.[11–13] Effective household-based methods to improve microbiologic water quality include chemical disinfection; solar, ultraviolet, and thermal processes; filtration devices; and combination technologies using multiple barrier approaches. Commercially produced porous ceramic "candle" filters have been found to not only improve drinking water quality but also reduce diarrheal disease in randomized, controlled trials in developing countries.[14,15]

The purpose of this study was to evaluate the microbiologic effectiveness and impact on diarrheal disease of a promising household water treatment technology, the Cambodian Ceramic Water Purifier (CWP), in a randomized controlled trial in a Cambodian village. This locally produced water filter is one version of the Potters for Peace *Filtrón* filter and has been previously described.[16,17] Similar versions of the CWP are now produced by the non-governmental organizations (NGOs) International Development Enterprises, Resource Development International-Cambodia (RDI), and the Cambodian Red Cross. Total countrywide production is approximately 6,000 units per month. Filters retail for ~US$8–10.[16]

METHODS AND MATERIALS

The interventions. In this study we examined the CWP as manufactured by RDI (Figure 1), which has been in production in Kandal Province since 2002. In the RDI process, locally sourced unfired clay bricks are milled and mixed with finely ground rice husks, press molded, and fired to cone 012 (~870°C) in a scrap wood-fueled masonry kiln. After flow testing to ensure that the flow rate is within the optimal range (1.5–3 L per hour at maximum head), the porous filters are painted with a 0.00215 molar reagent-grade (99.999%) $AgNO_3$ solution intended to inhibit microbial growth on filter media surfaces. Approximately 300 mL are applied to each filter element: 200 mL on the inside (46 mg Ag) and 100 mL on the outside (23 mg Ag).

The iron-rich ceramic (CWP-Fe) is a modified version of the RDI CWP that employs a high percentage (15% of dry weight) of goethite (FeOOH) in the ceramic base material. Data from initial laboratory testing of prototype filters suggested increased effectiveness in reducing viruses from limited volumes of spiked environmental waters (geometric

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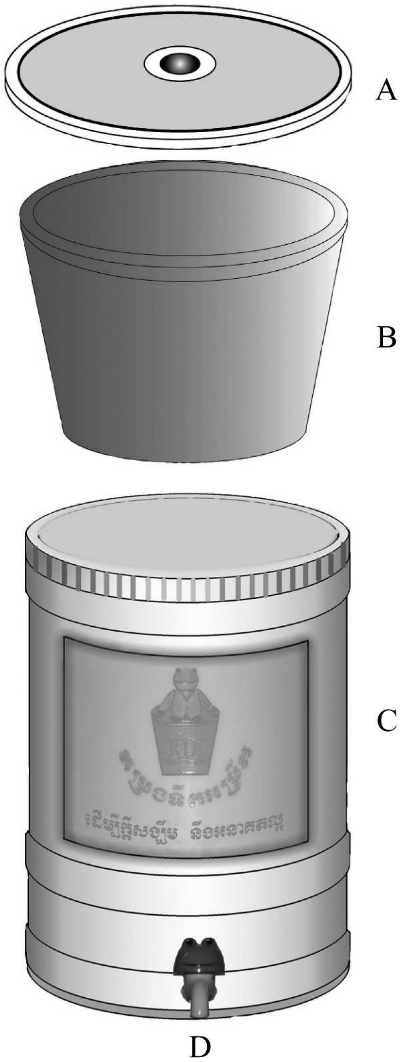

FIGURE 1. Schematic of the ceramic water purifier (CWP) as produced by Resource Development International—Cambodia (courtesy of Mickey Sampson). The complete filter unit consists of a lid (**A**) covering the porous, 10 L ceramic filter element (**B**) nested in the filter safe storage container (**C**). Treated stored water is collected via a tap at the base of the unit (**D**).

mean ≥ 99.99% reduction) compared with the CWP (Brown J, unpublished data). As a result, RDI has considered this alternative filter for full-scale production in Cambodia, and it was therefore included in the field trial as a separate study arm. Other specifics of manufacture, including mold pressing of filter pots, firing, flow testing, and silver nitrate treatment, were identical to the CWP.

Study site and selection of households. All households were located in Prek Thmey village, Kandal Province, Cambodia, ~10 km from the city of Phnom Penh on the Bassac River. Effluent from open wastewater canals serving Phnom Penh city flow into the Bassac River ~4 km upstream of the study area. Surface water, including heavily impacted Bassac River water, and harvested rainwater were the primary sources of drinking water for the community during the study period.

Global Positioning System (GPS) coordinates and other locating details were obtained for all village households within the district government-defined boundaries (613 households). The sample size for the study was computed as ~300 individuals or ~50 households (in each group) to detect a 20% difference in longitudinal prevalence of diarrheal disease (all) between each study group and a control group with 80% power and $\alpha = 0.05$, using methods for analysis of binary outcomes in multiple groups with repeated observations,[18] 60 households would be selected to allow for possible attrition. This level of reduction in diarrheal disease was considered conservative based on previous water quality intervention studies[11–13] and on one prospective cohort study of CWP interventions in Cambodia.[16] This study was not powered to detect any difference in diarrheal disease longitudinal prevalence between intervention groups, which was assumed to be less than 20%. Calculations account for limited clustering of outcomes within households and clustering in individuals over time, which are potentially important in the analysis of diarrheal disease data.[19,20]

Households were selected at random using a random numbers table and households were approached in group-randomized order (group size: 10 households) to determine eligibility for the trial. Eligibility criteria were: storage of drinking water at the household level, having one or more children < 5 years of age (up to 48 months at the time of enrollment; infants who were not yet drinking water were excluded from the study), household location within the village of Prek Thmey as defined by district authorities, and voluntary participation of the head of household and the primary caregiver (if a different person). Because diarrheal diseases disproportionately impact young children, including only households with children ensured that age-specific estimates of intervention impacts on diarrheal disease could be produced.

All eligible households were invited to participate in a 22-week study of household water treatment and health. Eligible households were recruited until the criterion of 180 households was met; four eligible households elected not to participate. Informed consent was obtained from the head of household and the household primary caregiver (defined as the primary caretaker for the children, responsible for household work and either responsible for or knowledgeable of household water management practices, usually an adult female) who acted as the main correspondent for the home in subsequent visits. In exchange for full participation in the study, all households received a CWP as manufactured by the RDI. Households were also supplied with several packets of UNICEF soluble oral rehydration salts at each household visit, regardless of whether households reported diarrheal disease. The study design and plan for household recruitment and informed consent were reviewed and approved by the University of North Carolina's Institutional Review Board and the Cambodian Ministries of Health and Rural Development.

Data collection. Participating households were visited eleven times altogether for water sample and survey data collection. After the baseline data collection phase comprising two household visits over four weeks, all households were randomly assigned to one of three groups of sixty households: 1) those receiving the CWP, 2) those receiving a CWP-Fe, and 3) a control group receiving no filter. Households receiving filters were trained in filter use and maintenance by a team from RDI and the study team, whereas control households were asked to maintain their normal routine for water collection, treatment, and storage. Data on water use and handling practices, sanitation and hygiene, household demographics, and other potentially important covariates were gathered during the baseline period and at each subsequent visit for all households. All survey instruments were prepared in both English and Khmer before being used in the study. They were pre-structured and pre-tested by back-translation from Khmer to English and used in pilot interviews and focus groups. Surveys used simple, straightforward language with predominantly closed (multiple choice) questions.

At each biweekly household visit, the primary caregiver was asked to provide a 7-day binary recall of diarrheal disease for herself and all members of the household, beginning with the day of the interview. Diarrhea was defined as three or more loose or watery stools in a 24-hour period. No attempt was made to measure case duration or to identify discrete case episodes.

Diarrheal disease burdens were estimated using longitudinal prevalence, or the proportion of total observed person-time with the disease outcome in individuals.[21] Longitudinal prevalence is a diarrheal morbidity measure that has been shown to be strongly correlated with risk of mortality in children < 5 years of age[22] and may be better correlated with nutritional status than incidence measures.[21,22] Longitudinal prevalence measures also possess practical and analytical advantages over incidence measures, because case frequency and duration data (often difficult to obtain) are not collected.[23,24] For these reasons, an increasing number of studies incorporate this measure in intervention trials.[25–27] Not all individuals were followed for the same amount of time in this closed cohort because of missing observations and loss to follow up, including death; longitudinal prevalence estimates for individuals were based on up to 63 days of post-baseline observation, with weighted estimates for those individuals contributing less follow up time. Because a 7-day recall period was used at each household visit and no data were collected on case duration or frequency, the longitudinal prevalence calculation for individuals had a resolution of seven days.

Longitudinal prevalence ratios (LPRs) were computed for each intervention group against the control group via a Poisson extension of generalized estimating equations (GEE), adjusting for clustering of diarrheal disease outcomes within households and within individuals over time.[28,29] The GEE model assumed that missing observations are missing completely at random (MCAR).[30] All statistical analyses were performed in Intercooled Stata 8.1 software (Stata Corporation, College Station, TX). All potential measured confounders, including water use and handling practices, socio-

TABLE 1
Selected characteristics of study groups from baseline survey

Characteristic	CWP group, $N = 60$	CWP-Fe group, $N = 60$	Control group, $N = 60$
Total number of people in group	395	398	403
Mean number of individuals per household	6.58	6.63	6.72
Number (%) female	211 (53%)	209 (53%)	211 (52%)
Number (%) children < 5 years of age	88 (22%)	81 (20%)	80 (20%)
Number (%) children 5–15 years of age	94 (24%)	90 (23%)	98 (24%)
Soap present in household*	50 (83%)	52 (87%)	50 (83%)
Self-reported total household income (USD/month)			
< $50	5 (8%)	10 (17%)	5 (8%)
$50–$99	16 (27%)	21 (36%)	25 (42%)
$100–$149	24 (41%)	18 (31%)	18 (30%)
$150–$200	13 (22%)	7 (12%)	11 (18%)
> $200	1 (2%)	3 (5%)	1 (2%)
Access to sanitation†	31 (52%)	31 (52%)	33 (56%)
Covered water storage container	32 (53%)	33 (55%)	34 (57%)
Wash hands with soap?‡	32 (53%)	32 (53%)	35 (58%)
Primary drinking water sources: dry season§			
Surface water	37 (62%)	31 (52%)	33 (55%)
Groundwater			
Deep well (≥ 10 m)	27 (45%)	30 (50%)	29 (48%)
Shallow well	0 (0%)	0 (0%)	0 (0%)
Rainwater	2 (3%)	0 (0%)	1 (2%)
Primary drinking water sources: rainy season			
Surface water	33 (55%)	31 (52%)	27 (45%)
Groundwater			
Deep well (≥ 10 m)	26 (43%)	28 (47%)	29 (48%)
Shallow well	1 (2%)	0 (0%)	0 (0%)
Rainwater	44 (73%)	39 (65%)	44 (73%)
Observed method of drawing water¶			
Use hands	36 (60%)	20 (33%)	27 (45%)
Pour or tap	24 (40%)	40 (67%)	23 (38%)
Formal education level of primary caregiver‖			
None	13 (22%)	10 (17%)	15 (25%)
Some or all primary school	38 (63%)	28 (47%)	27 (45%)
Some or all secondary school	6 (10%)	22 (37%)	17 (28%)
More than secondary (e.g., vocational)	3 (5%)	0 (0%)	1 (2%)

* Respondents were asked to demonstrate that soap was present in the household.
† Shared or own latrine (any type).
‡ Users who responded that they did wash hands "always" with soap at critical points such as after defecating.
§ Multiple answers possible. Most of the study took place in the rainy season. Respondents' own definitions of rainy and dry seasons were used.
¶ Respondents were asked to demonstrate their usual method of gathering water from the storage container.
‖ Usually an adult female who is responsible for child care.
CWP = ceramic water purifier; CWP-Fe = iron-rich ceramic; USD = U.S. dollar.

TABLE 2
Diarrheal disease longitudinal prevalence and filter effect estimates by age and sex of individuals

	Mean diarrhea longitudinal prevalence over 18-week intervention period*			Longitudinal prevalence ratio (LPR)† (95% CI)‡	
	Control	CWP	CWP-Fe	CWP	CWP-Fe
All persons	0.15	0.074	0.090	0.51 (0.41–0.63)	0.58 (0.47–0.71)
Age§					
< 5 years	0.23	0.14	0.19	0.58 (0.41–0.82)	0.65 (0.46–0.93)
5–15 years	0.13	0.079	0.078	0.62 (0.43–0.90)	0.48 (0.31–0.75)
≥ 16 years	0.12	0.045	0.091	0.37 (0.26–0.52)	0.57 (0.42–0.76)
Sex					
Male	0.12	0.076	0.081	0.61 (0.44–0.83)	0.60 (0.43–0.83)
Female	0.17	0.072	0.096	0.44 (0.33–0.58)	0.57 (0.44–0.75)

* Nine sampling rounds, June–October 2006; figures represent the proportion of individuals reporting diarrhea in the previous 7 days.
† The LPR was computed via Poisson extension of generalized estimating equations (GEE), adjusting for clustering of the outcome within households and within individuals over time.
‡ 95% confidence interval.
§ Age in years at the time of the first household visit.
CWP = ceramic water purifier; CWP-Fe = iron-rich ceramic.

economic status, and sanitation and hygiene-related factors, were assessed in the analytical model through a series of stepwise regression analyses with forward selection and backward elimination. Confounders were identified based on an *a priori* change-in-effect criterion of 10%.

Water samples of 250 mL volume were taken from each household in the study at each household visit to measure concentrations of fecal indicator bacteria and turbidity. Households in the intervention group were sampled for at least two types of water: untreated, stored household water and treated water as it was delivered via the filter tap. Samples from the control households were taken for analysis as well, and included their untreated water and current drinking water, if they used another water treatment method (e.g., boiling). If households used another source or treatment step for drinking water at the time of the visit, a sample of this water was also collected. The primary caregiver was asked to collect a sample of water in a sample collection container as if it were a household drinking cup. Samples were kept cool (4°C) and transported as quickly as possible to the laboratory in Kien Svay (~10 km distant), where analysis was performed as soon as possible, in all cases within 24 hours. *Escherichia coli* was quantified in water samples using membrane filtration (MF) via EPA method 1604[31] with concentrations reported as colony-forming units (cfu) per 100 mL. All samples were processed in duplicate using a minimum of two dilutions, three replicates each, with positive and negative controls. Turbidity of water samples was measured in triplicate using a turbidimeter (Hach Pocket) in the laboratory and reported as nephelometric turbidity units (NTU).

In addition to the household data collected on health and water quality, additional data on potential covariates were collected during household visits. Questions were asked to determine compliance with the household water intervention (water acquisition, treatment, storage, and use practices) and to document sanitation and hygiene conditions and practices. A variety of socio-economic data were collected on each household. Observational data, such as presence of soap in the home, types and numbers of water storage containers, and presence of animals or animal waste in the home, were collected to supplement interview data. All data were entered twice by separate data entry staff to minimize data entry errors.

RESULTS

The closed cohort included 180 households, with a total of 1,196 people (53% female, 21% < 5 years of age, mean household size: 6.6, median age: 19, range: 0–105 years at the time of first household visit). Four households (2%) were lost to follow up, two in each intervention group. Selected baseline characteristics for all households are presented in Table 1.

Stratified estimates of diarrheal disease longitudinal prevalence by study group are presented in Table 2 and Figure 2. A clear reduction in diarrheal disease was observed in intervention (CWP and CWP-Fe) households compared with control (non-filter) households, in all age groups and both sexes. The adjusted LPR effect estimate for the CWP for all ages was 0.51 (95% CI: 0.41–0.63), corresponding to a mean reduction in diarrheal disease of 49%, after controlling for clustering within households and within individuals over time, and 0.58 (95% CI: 0.47–0.71) for the CWP-Fe. Among children < 5 years of age (0–48 months at the first household visit), adjusted LPRs were 0.58 (95% CI: 0.41–0.82) for the CWP and 0.65 (95% CI: 0.46–0.93) for the CWP-Fe.

Filters improved drinking water quality at the point of use: 59% of CWP filtrate samples were under 10 *E. coli*/100 mL, with 40% of samples having < 1 *E. coli*/100 mL. Sixty-two percent (62%) of CWP-Fe filtrate samples were under 10 *E.*

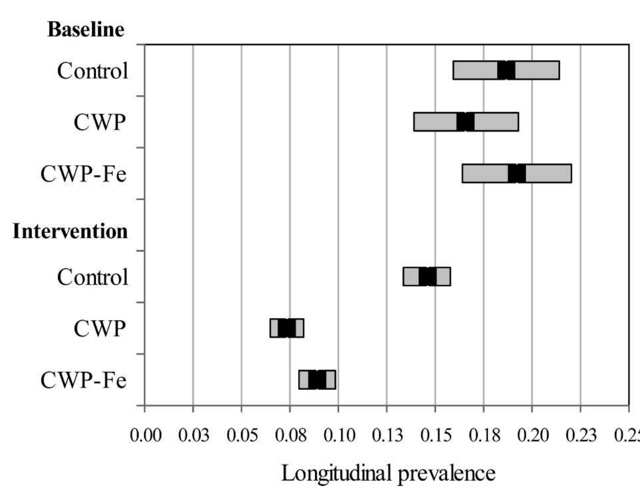

FIGURE 2. Diarrheal disease longitudinal prevalence by group and study phase. Bars represent 95% confidence intervals (CI).

coli/100 mL, with 37% of samples having < 1 *E. coli*/100 mL. Eighty-five percent (85%) of household drinking water samples from control households were considered higher risk (≥ 101 cfu/100 mL *E. coli*) versus 20% of samples from CWP intervention households and 21% of CWP-Fe intervention households (Table 3). A summary of means of *E. coli* counts and turbidity in intervention and control household samples (both treated and untreated water) is presented in Table 4. Both the CWP and CWP-Fe filters reduced *E. coli* in household drinking water by a mean of ~96%, or 1.4 $\log_{10}$, over the course of the 18-week field trial. No significant differences in microbiologic effectiveness were detected between filters.

Measured covariates were examined for possible independent associations with diarrheal disease after controlling for the presence of the intervention (CWP or CWP-Fe) and clustering within individuals over time and within households. Factors associated with decreased diarrheal disease were: the caregiver reporting hand washing at critical times such as after defecating, after cleaning a child, and before preparing food (LPR = 0.77, 95% CI: 0.65–0.92) and living in a house with a tile roof (a positive wealth indicator) (LPR = 0.69, 95% CI: 0.55–0.86). Higher diarrheal disease was reported in those < 5 years of age (0–48 months at the first study visit) (LPR = 2.1, 95% CI: 1.8–2.5) compared with older individuals.

DISCUSSION

This study constitutes the first randomized, controlled trial of locally produced ceramic water filters for POU drinking water treatment. In this study, household-level access to either ceramic water filter resulted in a marked decrease in diarrheal disease among users versus a control group without filters, an effect that was observed in all age groups and both sexes after controlling for clustering of the outcome within households and within individuals over time.

More time allocated to follow-up is likely to increase the accuracy of disease outcome estimates, but repeated household visits are often cost-prohibitive and may lead to study fatigue in participants.[21] A period of 72 days of observation time is needed to reliably estimate the longitudinal prevalence of diarrheal disease in individuals (not groups), according to one analysis.[32] In this study, the baseline phase comprised 14 days of observation and the intervention phase 63, with reduced resolution from the use of binary outcome coding for the 7-day follow-up period rather than data recorded on a daily basis. Group data, however, were the focus of this study, and in the context of this study using a closed cohort, longitudinal prevalence may be interpreted as mean prevalence for the group during the recall period.[21] Recall periods of greater than 48 hours may lead to underreporting of cases,[21,33,34] although 7-day recall periods are common in practice.[13] Logistical and resource limitations restricted the number of total household visits in this study, necessitating the use of 7-day recall to capture sufficient time at risk for participants.

Filters were also associated with significantly improved household drinking water quality. No significant differences in microbiologic effectiveness or health impact were observed between the candidate filters, although this study was not powered to specifically address these points. Both filters reduced *E. coli* in stored, untreated water by a geometric mean 96% from pre-treatment levels, delivering consistently improved household drinking water to users compared with a control group. A small number of filtered water samples (4.9% of CWP samples, 5.0% of CWP-Fe samples) showed a greater concentration of *E. coli* in treated water than in stored (untreated) water samples, possibly due to filtered water storage container contamination during improper handling or cleaning practices as has been reported previously.[16]

Seasonal effects on diarrheal disease prevalence or microbiologic water quality were not accounted for in this study because of its limited duration. The study period was unusually wet, and although data from relatively brief dry periods were included, there were insufficient dry-season data to present a stratified analysis by season or by wet versus dry weather conditions. Water use practices, water treatment practices, diarrheal disease rates, and the presence of microbial pathogens and indicators in potential drinking water sources can vary greatly by season.[35,36]

Compliance or proper use of the technology has been associated with greater associated health impacts for water quality interventions.[13] Users reported a high level of compliance throughout the study, with 98% of filters in use at all visits and 100% of users responding that the filter was used for "all household drinking water." Direct observational data on filter use was not attempted, however, and the high reported compliance could have been the result of repeated observations by the data collection team (e.g., the Hawthorne Effect) and encouragement of consistent use by the partner NGO.

The principal limitation of this study and the major deficiency of the literature on water quality interventions generally, was the lack of any placebo (sham) filter device as a comparative group. Our NGO partner objected to the use of a sham filter because of ethical concerns,[37] including 1) the possibility of undermining community trust in this emerging market for ceramic filters; 2) concern that users would change their water use behavior to switch from boiling to using the filter, even though in our intervention trials we never discour-

TABLE 3

Measured levels of *E. coli* (cfu/100 mL) in household drinking water by study group

	Number (%*) of all samples by *E. coli* concentration of household drinking water†					
Study group	0 (cfu/100 mL)	1–10 (cfu/100 mL)	11–100 (cfu/100 mL)	101–1,000 (cfu/100 mL)	1,001 + (cfu/100 mL)	Total samples‡
Control households	6 (1%)	20 (3%)	65 (11%)	294 (49%)	221 (36%)	606
CWP	243 (40%)	116 (19%)	121 (20%)	87 (14%)	37 (6%)	604
CWP-Fe	228 (37%)	152 (25%)	102 (17%)	79 (13%)	49 (8%)	610

* Percentages within strata may not add up to 100% because of rounding.
† Samples were filter effluent in intervention households and stored household drinking water for control households (including samples from treatment by boiling). Households were asked to provide a sample of the water that the family was drinking at the time of visit.
‡ Incomplete data for 54 (8%) control households, 56 (8%) for ceramic water purifier (CWP) households, and 50 (8%) for iron-rich ceramic (CWP-Fe) households.

TABLE 4
Mean *E. coli* counts (cfu/100 mL) and turbidities for samples taken in study households (untreated and treated water)

	Water quality data,* means (95% CI†) (untreated water)		Water quality data,* means (95% CI†) (treated water)	
	E.coli/100 mL	Turbidity (NTU)	*E.coli*/100 mL	Turbidity (NTU)
Control				
Arithmetic	3,000 (2,500–3,500)	11 (10–12)		
Geometric	600 (570–640)	5.5 (5.3–5.6)		
CWP				
Arithmetic	3,500 (3,000–4,000)	7.5 (7.1–8.0)	110 (46–170)	3.1 (2.7–3.5)
Geometric	520 (490–550)	4.8 (4.7–5.0)	17 (14–22)	2.4 (2.3–2.5)
CWP-Fe				
Arithmetic	1,800 (1,500–2,000)	8.7 (8.3–9.2)	110 (60–170)	3.1 (2.3–3.8)
Geometric	420 (400–450)	5.2 (5.1–5.3)	15 (12–18)	2.3 (2.2–2.4)

* Data from intervention households, raw (untreated) water and filtered (treated water) samples from 9 sampling rounds.
† 95% confidence intervals.
NTU = nephelometric turbidity units; CWP = ceramic water purifier; CWP-Fe = iron-rich ceramic.

age boiling; and 3) concern that study participants could not give true informed consent for a placebo intervention, because the concept of a placebo is not well understood in the population.[38,39] No blinded (placebo-controlled) intervention trials of household water treatment have yielded clear evidence of positive health impacts on users.[13]

Although universal access to a microbiologically and chemically safe, piped water supply system with individual household connections is the ultimate goal, POU technologies have the potential to fill the service gap where piped water systems are inadequate or inaccessible, potentially resulting in substantial positive health impacts in developing countries.[40] Data reported here suggest that locally produced ceramic filters are a promising low-cost, effective water treatment technology that merits further study. As is the case with all such interventions, critical evaluation of the CWP's long term impact on water quality and human health is needed to inform current and potential users, implementers, and decision makers. Particularly needed are blinded studies using sham filter devices, further investigation into microbiologic effectiveness of existing locally produced filters to document and increase reduction efficiencies of waterborne pathogens, and market and implementation research to examine possibilities for scale-up to increase coverage. Long-term and large-scale studies are needed to ensure that ceramic filters and other POU drinking water interventions can provide consistent, reliable, and low-cost access to safe drinking water.

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