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Follow-Up Study to Assess the Use and Performance of Household Filters in Zambia

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Abstract. Effective household water treatment can improve drinking water quality and prevent disease if used correctly and consistently over time. One year after completion of a randomized controlled study of water filters among households in Zambia with children < 2 years old and mothers who were human immunodeficiency virus (HIV)-positive, we conducted a follow-up study to assess use and performance of new filters distributed at the conclusion of the study; 90% of participating households met the criteria for current users, and 75% of participating households had stored water with lower levels of fecal contamination than source water. Microbiologically, the filters continued to perform well, removing an average of 99.0% of fecal indicator bacteria. Although this study provides some encouraging evidence about the potential to maintain high uptake and filter performance, even in the absence of regular household visits, additional research is necessary to assess whether these results can be achieved over longer periods and with larger populations.

INTRODUCTION

Unsafe drinking water is a major cause of diarrheal death and disease, especially for young children in low-income countries and people living with human immunodeficiency virus (HIV)/acquired immunodeficiency syndrome (AIDS).[1,2] Diarrheal disease and unsafe drinking water may be particularly debilitating for young children born to HIV-positive mothers.[3–5] Our previous research in Zambia found that children < 2 years old born to HIV-positive mothers are particularly at risk of diarrheal disease.[6]

Improving household drinking water quality through household water treatment and safe storage (HWTS) has been shown to have the potential to significantly reduce diarrheal disease.[7–9] However, although research has shown the need for consistent use of these interventions,[10,11] there are questions about whether HWTS interventions are used correctly and consistently over an extended period of time.[12,13] Overall, there is limited follow-up data on randomized controlled trials (RCTs), and existing evidence suggests that HWTS use and health impact may decline over time.[7,14]

We previously undertook a 1-year RCT in Chongwe District, Zambia, to assess the HWTS filtration technology LifeStraw Family Filter ® (Vestergaard-Frandsen SA, Suzhou, Jingsu, China) combined with two 5-L local jerry cans for safe storage.[15] In the RCT, filter use was high, with 96% of household visits meeting the criteria for users. The filters were also microbiologically effective, reducing thermotolerant coliforms (TTCs; a fecal indicator) by 99.4% and providing intervention households with significantly improved water quality compared with control households (geometric mean of 3 versus 181 TTC per 100 mL, respectively; $P < 0.001$). At the end of the RCT in August of 2011, the control group received filters and storage containers along with the manufacturer's instructions for use and maintenance; the intervention group was also given the option to have their filter replaced with a new one, and all but two households chose to receive new filters.

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We undertook this follow-up study to assess filter use and microbiological performance 1 year after completion of the study.

METHODS

Study population and recruitment. All 101 study households that completed the RCT were eligible to participate in the follow-up study. We recruited participants by visiting the households previously enrolled in the RCT, providing complete details regarding the follow-up study, and asking for written consent. Participating households received one unannounced visit during October or November of 2012 (Figure 1), just over 1 year after completion of the RCT. Neither the research team nor anyone else to our knowledge had any other contact with study participants concerning filter use during this 1-year period, although some of the RCT fieldworkers continued to reside and work in the project area after the project was terminated.

Filter use and acceptability. Filter use and acceptability were assessed using household questionnaires and observations similar to those household questionnaires and observations used in the RCT. Households were classified as reported users if all three of the following conditions were met: (1) the filter was observed in the household at the time of visit, (2) the storage vessel contained water reported to be treated at the time of visit, and (3) the respondent reported using the filter on the day of or day before the day of visit. Households were classified as confirmed users if, in addition to these three criteria, there was at least a 1 $\log_{10}$ (90%) improvement in TTC in their stored household water over their unfiltered water or stored water quality was < 10 TTC/100 mL. Exclusive users were those users who did not drink any unfiltered water the day of and day before the visit, which was reported by the mother. We used χ^2 tests to examine associations between household use and demographics, including socioeconomic status, household size, mother's education, mother's age, mother's marital status, mother on antiretroviral therapy, water source, sanitation facility, and soap present (cofactors were defined as previously described[15]).

Flow rate. We also measured flow rate from the filters to examine the impact of use over time. Flow rate was assessed by filling the filter to the fill line, opening the tap,

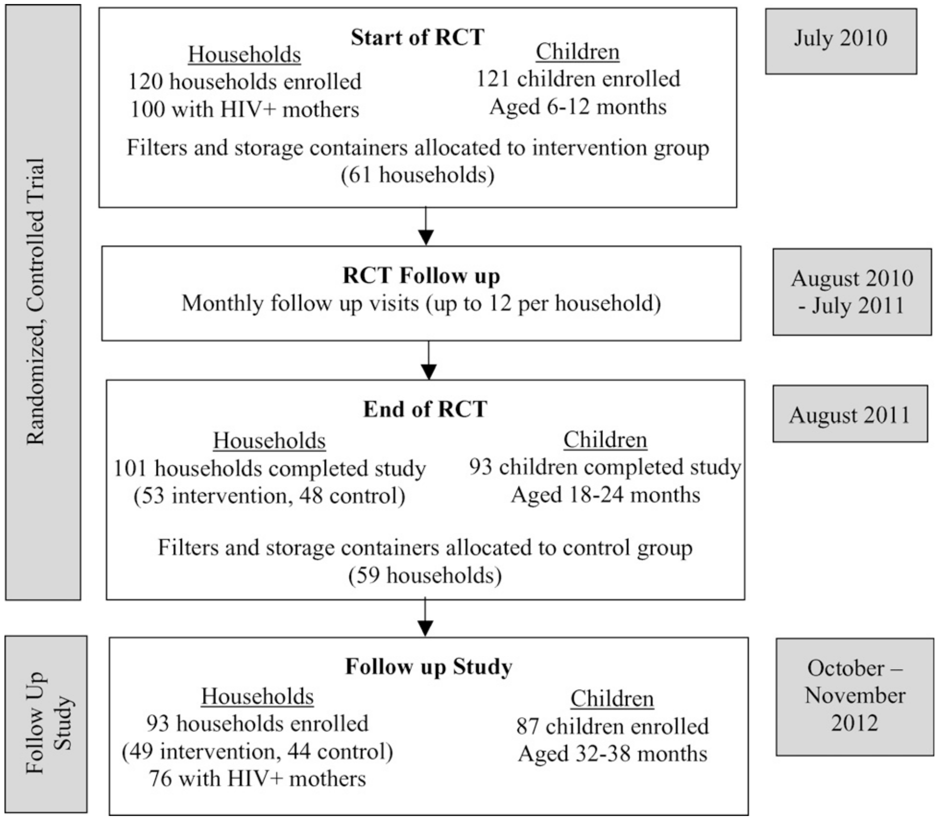

FIGURE 1. RCT and follow-up study overview.

and measuring the time that it took to yield 100 mL. The design rate is 150 mL/minute (9.0 L/hour). Previous laboratory testing showed a mean flow rate of 146 mL/minute (8.8 L/hour) over 20,000 L.[16]

Microbiological performance. Filter performance was evaluated through bacteriological water testing using the same sampling and analytical methods used in the RCT. For each household, samples were collected of (1) unfiltered water stored in the home (influent water), (2) filtered water immediately after filtration (effluent water), and (3) stored water that the household reported to be filtered, if available. For 4.1% (11/267) of plates that were too numerous to count (TNTC), we ascribed a value of 500 coliform-forming units (CFUs) per 100 mL (the upper detection limit).

Data analysis. Data was entered into Excel and analyzed using Stata 12. To assess filter use, data were tabulated by RCT group to examine whether there was a difference between our original control and intervention households. To assess filter performance, TTC counts were normalized with $\log_{10}$ transformations; a value of one was added to all TTC levels before transformation to account for samples with TTC values of zero ($\log_{10}$ [TTC level + 1]). Microbiological filter performance was calculated as the difference of the $\log_{10}$ of the influent concentration and $\log_{10}$ of the effluent concentration. Differences in mean TTC counts and use by RCT group were assessed for significance using paired Student *t* tests.

Ethics. Ethical approval for this follow-up study was obtained from the Ethics Committee of the University of Zambia. Ethical approval from London School of Hygiene and Tropical Medicine was covered under our RCT ethical approval. Informed written consent was obtained from all participants.

RESULTS

Study population. Of 101 possible households that completed the RCT, 93 (92%) households participated in the follow-up study. Six former participants had moved, one mother had died, and one mother refused. In total, 93 households included 495 individuals, 76 households with HIV-positive mothers, and 87 children from the original RCT (age 32–38 months at the time of follow-up). Participating households included 49 of 53 potential households from the RCT intervention group and 44 of 48 potential households from the control group. Details on demographics are reported with the RCT results.[15] The follow-up study cohort was comparable with the RCT cohort on demographic characteristics; however, the follow-up study cohort had a larger percentage of households using unprotected dug wells (72.2% versus 51.7%). Water sources were primarily unprotected dug wells (72.2%, 65/90), although other sources included public taps (17.8%, 16/90), boreholes (8.9%, 8/90), and private taps (1.1%, 1/90; data missing for three households). New filters had been received by 97.8% (91/93) of households in August of 2011 at the end of the RCT (Figure 1). Two households in the intervention group elected to keep the filter that they used during the trial rather than have it replaced (received July of 2010).

Filter use and acceptability and flow rate. Most households were using the filters (Table 1). Reported use did not vary

Table 1
Filter use and acceptability

	RCT intervention group		RCT control group		Total	
	N	Percent	*N*	Percent	*N*	Percent
Filter use						
Reported user*	46/49	93.9	38/44	86.3	84/93	90.3
Confirmed user†	32/49	65.3	35/44	79.6	67/93	72.0
Exclusive use by mother today/yesterday‡	41/49	83.7	40/44	90.9	81/93	87.1
Exclusive use by child today/yesterday‡	37/45	82.2	38/42	90.5	75/87	86.2
Filter present in household	47/49	95.9	41/44	93.2	88/93	94.6
Filtered water for drinking today/yesterday	46/49	93.9	39/44	88.6	85/93	91.4
Currently have filtered water stored	47/49	95.9	40/44	90.9	87/93	93.6
Always used filter in past week	47/49	95.9	41/44	93.2	88/93	94.6
Stored filtered water was ≥ 1 $\log_{10}$ TTC lower than unfiltered water or quality was < 10 TTC/100 mL	35/49	71.4	40/44	90.9	75/93	80.7
Median number of times filling filter per day (range)	2 (2–8)		2 (0.5–8)		2 (0.5–8)	
Median volume of filtered water used per day, L (range)	15 (5–30)		15 (10–30)		15 (5–30)	
Median flow rate, L/hour (range)	5.6 (2.1–13.8)		4.9 (3.3–17.1)		5.2 (2.1–17.1)	
What people like best about the filter§						
Provides safe water	41/47	87.2	36/40	90.0	77/87	88.5
Improves water taste	36/47	76.6	30/40	75.0	66/87	75.9
Provides good water	16/47	34.0	11/40	27.5	27/87	31.0
Easy to use	8/47	17.0	6/49	15.0	14/87	16.1
What people like least about the filter¶						
Nothing (everything is okay)	45/47	95.7	41/42	97.6	86/89	96.6
Flow rate is too slow	1/47	2.1	0/42	0.0	1/89	1.1
Filter has been eaten by rats	1/47	2.1	1/42	2.4	2/89	2.3
Filter maintenance‖						
Backwashed today or yesterday	46/49	93.9	37/44	84.1	83/93	89.2
Cleaned pre-filter today or yesterday	46/49	93.9	41/44	93.2	87/93	93.5
Water storage						
Using storage container provided	34/49	69.4	31/44	72.1	65/93	70.5
Storage container capped	22/49	44.9	27/44	61.4	49/93	52.7
Only store filtered water in provided containers	28/49	57.1	26/44	59.1	54/93	58.1

*Households were classified as reported users if (1) the filter was observed at the time of visit, (2) the storage vessel contained water reported to be treated, and (3) the respondent reported using the filter the day of or day before the visit.

†Households were classified as confirmed users if, in addition to the criteria for reported users, there was at least a 1 $\log_{10}$ TTC improvement in stored household water over unfiltered water or stored water quality was < 10 TTC/100 mL.

‡Exclusive use was defined as not drinking any unfiltered water the day of and day before the visit, which was reported by the mother. Reasons for drinking unfiltered water were that they were away from home (eight people), they did not have time to filter (three people), and the filter was not working (one person). For children < 2 years old, six children died during the RCT, and therefore, data are missing.

§Data missing for six households.

¶Data missing for four households.

‖Households were instructed to backwash and clean the pre-filters daily as recommended by the manufacturer.

significantly between the RCT intervention and control groups (P = 0.40), although confirmed use was of borderline significance (P = 0.08). Overall, 90.3% (84/93) of households were classified as reported users, and 72.0% (67/93) of households were classified as confirmed users. If we restrict our definition of confirmed users to only those users who had at least 1 $\log_{10}$ removal, 64.5% (60/93) of households would still be considered confirmed users. For households that did not meet the criteria of confirmed users, 10.8% (10/93) of households had stored water of somewhat better water quality compared with unfiltered water (< 1 $\log_{10}$).

Five households (5.4%) did not have the filter set up for use at the time of visit; two households reported that they did not have time to filter, one household head reported that she had been away from home, one filter was rendered inoperable by rats, and one household head had given the filter to a neighbor for safe keeping. With the exception of these five households, all reported that everyone drinks filtered water when at home. Only 2 (2.2%) of 93 filters had problems. Both had parts that were eaten by rats, although one filter was still functional. No households reported clogging problems.

Exclusive use was reported by 87.1% (81/93) of mothers, and exclusive use was reported for 86.2% (75/87) of children. Reasons for drinking unfiltered water were that they were away from home (eight households), they did not have time to filter (three households), or the filter was not working (one household). Only 3.2% (3/93) of households reported that anyone in the household took water to school or work.

The storage containers provided during the RCT were used in 70.5% (65/93) of households; however, they were capped in only 52.7% (49/93) of households. Capped storage containers were less common in households that had the containers for 2 years (45% in the RCT intervention group) compared with households that had the containers for 1 year (61% in the RCT control group; P = 0.11). Reported reasons for not using the storage containers were that the container was stolen (12 households), was broken (8 households), did not provide enough water (2 households), was used for other purposes (1 household), was lent to neighbor/family (1 household), was eaten by rats (1 household), and was lost (1 household; data missing for 2 households). All 28 households not using the provided storage containers were storing water in buckets and obtaining water by dipping cups.

When examining cofactors associated with use, larger households (more than six members) were more likely to be reported users (100% [36/36], P = 0.008) and confirmed users (86.1% [31/36], P = 0.011) compared with smaller households (82.5% [47/57] and 61.4% [35/57], respectively). Households with unimproved water sources were more likely to be confirmed users (76.9% [50/65] versus 52% [13/25], P = 0.021) but not reported users ($P = 0.36$). Mother's education level was borderline significant with capped storage container use ($P = 0.065$).

The flow rate was an average (median) of 87 mL/minute (5.2 L/hour) and ranged from 35 mL/minute (2.1 L/hour) to 285 mL/minute (17.1 L/hour).

Water quality. Unfiltered water samples were collected in all households; filtered samples and stored filtered samples were each collected in 93.5% (87/93) of households. Water quality did not vary significantly between RCT intervention and control groups for unfiltered water ($P = 0.26$), filtered water ($P = 0.54$), or stored filtered water ($P = 0.15$); therefore, combined results are presented (Table 2).

Overall, 75.3% (70/93) of households had stored water of better water quality compared with unfiltered water. Water quality was significantly better in filtered samples (geometric mean of 1.7 TTC/100 mL, $P < 0.0001$) and stored filtered samples (geometric mean of 6.1 TTC/100 mL, $P < 0.0001$) compared with unfiltered samples (geometric mean of 166 TTC/100 mL). However, stored filtered samples were significantly more contaminated compared with filtered samples (geometric mean of 6.1 versus 1.7 TTC/100 mL, respectively; $P < 0.0001$). The geometric mean removal from influent (unfiltered) to effluent (filtered) was 2.0 $\log_{10}$ TTC/100 mL (95% confidence interval [95% CI] = 1.8–2.2 $\log_{10}$ TTC/100 mL), corresponding to a 99.0% (95% CI = 98.3%–99.4%) reduction.

DISCUSSION

In a follow-up study among households that received water filters more than 1 year before for participation in an RCT, 9 of 10 households were using the filters, and 7 of 10 households benefited from improved drinking quality. More than 8 in 10 of mothers reported that they and their children drank treated water exclusively, although this measure had no objective indicator and is subject to reporting bias. These rates are comparable with the rates observed among the intervention households in the RCT, despite the lack of the regular household visits by investigators that took place during the trial.[15] We found no difference in filter use or performance among members of RCT study arms, suggesting that uptake was high, even among households using filters for more than 2 years. However, confirmed use was lower in the RCT intervention arm, although results were of borderline significance ($P = 0.08$). Although flow rates suggest that filters were still capable of meeting the volume requirements for household drinking water, flow rates were lower than design or laboratory results, a possible indication of suboptimal backwashing or partial clogging in some cases. Microbiologically, the filters continued to perform well, removing an average of 99.0% of fecal indicator bacteria compared with 99.4% of fecal indicator bacteria in the RCT.

Larger households (more than six members) were more likely to be users; it is possible that larger households had more people to contribute to the activity of filtering water. Households with unimproved water sources were more likely to be confirmed users but not reported users; however, this finding may be because households with poorer water quality were more likely to meet the criterion of at least a 1 $\log_{10}$ (90%) improvement in TTC in their stored household water over their unfiltered water.

There was a decline in storage container use compared with results during the RCT; 71% of households reported using the provided storage containers, and only 53% of households capped the provided containers (100% and 98% at the final RCT visit, respectively). Because safe storage is essential to maintain the microbiological quality of filter water that does not have a residual disinfectant, it is possible that some households that were using the filter did not meet the water quality criterion for confirmed users. The lower use of capped containers in the RCT intervention group compared with the RCT control group indicates a decline in use over time.

Other HWTS programs have found a decline in use over time. An evaluation of a household chlorination intervention found that reporting household water treatment dropped from 70% at the end of the intervention to 37% 6 months later.[12] However, there is some evidence that use is particularly high for filtration compared with other HWTS technologies[13,17]; in a follow-up project of biosand filters at least 5 years old, use was found to be 70%.[18] Furthermore, use may be particularly high among HIV-positive mothers with young children because of increased concern and awareness of health; chlorination use has been found to be high among similar populations.[19,20] It is also possible that filter use was higher because local health staff used during the RCT continued to reside and work in the project areas after that RCT terminated.

Evidence suggests that the potential health benefits offered by effective HWTS are not possible in the absence of correct, consistent, and sustained use of HWTS. This follow-up study provides some encouraging evidence about the potential to maintain high uptake and filter performance, even in the absence of regular household contact by researchers or implementers. Because the filters were designed to be used for

Table 2
Water quality

	Unfiltered samples ($N = 93$)	Filtered samples ($N = 87$)	Stored filtered samples ($N = 87$)
Fecal contamination (TTC/100 mL)			
< 1	9 (9.7%)	66 (75.9%)	49 (56.3%)
1–10	8 (8.6%)	13 (14.9%)	14 (16.1%)
11–100	26 (28.0%)	6 (6.9%)	7 (8.1%)
101–1000	24 (25.8%)	2 (2.3%)	11 (12.6%)
> 1,000	26 (28.0%)	0 (0.0%)	6 (6.9%)
Geometric mean TTC/100 mL	166 (95% CI = 97–286)	1.7 (95% CI = 1.3–2.3)	6.1 (95% CI = 3.5–10.5)
Samples with > 100 TTC/100 mL	50 (53.8%)	2 (2.3%)	17 (19.5%)
Mean $\log_{10}$ removal	N/A	2.0 (95% CI = 1.8–2.2)	1.5 (95% CI = 1.2–1.7)
Samples with > 1 $\log_{10}$ removal	N/A	77 (88.5%)	60 (69.0%)

N/A = not applicable.

at least 3 years, it would be valuable to conduct additional follow-up studies of this population. Additional research is necessary to assess whether these results can be achieved over longer periods and with larger populations.

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