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Research Article

Clinical and Microbiologic Efficacy of a Water Filter Program in a Rural Honduran Community

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Water purification in the rural Honduras is a focus of the nonprofit organization Honduras Outreach Medical Brigade Relief Effort (HOMBRE). We assessed water filter use and tested filter microbiologic and clinical efficacy. A 22-item questionnaire assessed water sources, obtainment/storage, purification, and incidence of gastrointestinal disease. Samples from home clay-based filters in La Hicaca were obtained and paired with surveys from the same home. We counted bacterial colonies of four bacterial classifications from each sample. Sixty-five surveys were completed. Forty-five (69%) individuals used a filter. Fifteen respondents reported diarrhea in their home in the last 30 days; this incidence was higher in homes not using a filter. Thirty-three paired water samples and surveys were available. Twenty-eight samples (85%) demonstrated bacterial growth. A control sample was obtained from the local river, the principal water source; number and bacterial colony types were innumerable within 24 hours. Access to clean water, the use of filters, and other treatment methods differed within a geographically proximal region. Although the majority of the water samples failed to achieve bacterial eradication, water filters may sufficiently reduce bacterial coliform counts to levels below infectious inoculation. Clay water filters may be sustainable water treatment measures in resource poor settings.

1. Introduction

Worldwide, over 1 billion people lack access to improved sources of drinking water. The lack of potable water greatly contributes to the presence of water-related illness, especially in developing countries [1].

Many communities in Honduras lack access to clean water. This is especially true in rural areas; approximately ninety-nine percent of the country's urban population has access to improved water compared to eighty-two percent of the country's rural population [2]. As much as ninety percent of rural water supplies in Honduras come from intermittent or unreliable sources [3], and water purification efforts reach sixty percent of the country's total population, yet only fifty percent of the country's rural communities [3].

Worldwide, diarrhea is among the leading causes of mortality in children under the age of five. Availability of clean water has previously been associated with lower mortality and a lower risk of child diarrhea [4]. The lack of clean drinking water in rural Honduran communities results in a large potential for the development of waterborne illnesses and potential death in infants and young children. Diarrhea accounted for seven percent of deaths in children under five in Honduras in 2010 [5]. A discrepancy exists in the infant mortality rate in children younger than five between urban Honduran communities (twenty-nine percent) and rural Honduras (forty-three percent) [5] and may be partly consistent with the differences in access to clean drinking water as well as other differences between the two communities.

Point-of-use (POU) technologies are interventions that provide clean water to homes where public water treatment is unavailable. Household based clay water filters are a POU mechanism with the potential to reduce diarrheal illness.

Figure 1: La Hicaca, Northern Honduras.

Beginning in the late 1980s and early 1990s, ceramic filters began to appear in poor communities in developing countries as a means of providing clean drinking water [6]. These devices reduce the levels of turbidity and bacteria in water by ninety-nine percent [7]. Water flows through the filter, impregnated with colloidal silver, at a flow rate of one to two liters per hour. As the water flows through the pores in the clay, bacteria and other turbidities become trapped and the antimicrobial properties of the silver impede the growth and replication of bacteria [8]. Previous field studies demonstrated decreased risk and incidence of gastrointestinal disease following implementation of water filter use, though further testing was necessary for conclusive results [9].

The Virginia Commonwealth University Global Health and Health Disparities Program (GH2DP) and the Honduras Outreach Medical Brigade Relief Effort (HOMBRE), a university affiliated medical relief program, began the distribution of water filters in 2008 in the rural Honduran town of La Hicaca (Figure 1) [10]. These filters are made in country by local artisans following Potters for Peace guidelines. For approximately twenty-five dollars per filter, a family has access to clean drinking water for a minimum of two years. Previous work by HOMBRE missions revealed that, among those without access to clean or filtered water, water treatment and nutrition were the main health concerns [11]. Surveys administered by the 2011 brigade in La Hicaca reported the use of a home water filter by forty percent of respondents [12]. However, the clinical and microbiologic efficacy of the filters provided by HOMBRE is unknown.

2. Objectives

The purpose of this study was to assess drinking water sources, methods of water treatment, water filter use, and self-reported incidence of diarrhea in the rural Honduran community La Hicaca as well as in 17 geographically proximal villages with a total population of approximately 2000. Additionally, microbiologic testing of water filters was completed to assess their effectiveness in the eradication of microorganisms.

3. Methods

3.1. Survey and Interviewing. The VCU Institutional Review Board approved a 22-item questionnaire. The questionnaire was administered in Spanish at the HOMBRE clinic site of La Hicaca in June 2012. Eligible subjects were any Spanish-speaking individual over the age of 18 seeking care at the HOMBRE clinic in La Hicaca during June 2012. The questionnaire addressed four areas pertinent to water use. Four questions addressed water sources and their frequency of use. These questions employed multiple-choice answers. Seven multiple-choice questions addressed water obtainment and storage. Seven questions addressed water purification, including the use of a water filter as well as additional methods of treatment. Of these seven questions, five were multiple-choice and the remaining two used a Likert scale to identify the frequency of use of a particular treatment method as "always," "most of the time," "some of the time," "hardly ever," or "never." The final four questions addressed the incidence of gastrointestinal disease within the preceding thirty days in the home of the survey respondent: three were multiple choice questions and the final used a Likert scale to assess the degree of agreement that using a water filter resulted in less diarrhea in the home within the last year. Diarrhea was defined as three or more loose stools in a period of twenty-four hours [13].

The study was completed over five clinical encounter days. The author (Jaclyn Arquiette) conducted each interview, assisted during several interviews by trained, bilingual team members. Interviews were conducted using convenience-sampling methodology. Each survey was administered as a structured individual interview. Survey responses were collected on paper.

3.2. Statistical Analysis. Survey responses were analyzed using SAS statistical software (version 9.2, SAS Institute, Inc., Cary, NC). A descriptive analysis of the data was conducted using mean values, frequency counts, and percent response where applicable. A 2-way chi-squared test of significance was employed to determine a difference in response across homes with and without water filters as well as across homes from La Hicaca and the other villages.

3.3. Water Filter Sampling. All water samples were tested for the presence of coliform bacteria using Coliscan Easygel kits [14]. Samples were collected over a period of three days. Five milliliters from each sample was added to the Coliscan gel. The mixture was shaken by hand and poured into individual plates. Each sample incubated for the same amount of time (24 hours) at room temperature before being read. At the time of reading, four types of bacterial colonies were counted and the results were recorded on site.

A sample was collected from the local river/stream and a public spigot to serve as controls. After incubation, the number of bacterial colonies on each plate was counted and recorded. For standardization purposes, innumerable colonies were recorded as "innumerable," "too many to count," or "too smeared to count." The controls collected from the public spigot and the local stream both had innumerable bacterial colonies growing at the time of recording. In subsequent analysis these counts were recorded as greater than the highest countable number of colonies. Following

the instructions provided in the Coliscan kit, [14] colony counts were converted to the number of colony forming units (CFU) per one hundred milliliters (CFU/100 mL) by dividing 100 by the number of milliliters of the sample (5) and multiplying that result by the number of colonies detected on the plate. The number of samples growing each type of colony was recorded ($n = x$) below the specific classification of bacteria. Samples with an individual colony type that had an innumerable number of colonies growing are noted as 10000+.

3.4. Linkage of Water Filter Sampling and Surveys. HOMBRE maintains records of distributed household based clay water filters. These records contribute to an organized system for present and future filter distribution. For the purposes of water filter sampling, a registry of homes in La Hicaca that received a water filter in 2010 or 2011 was utilized to identify homes from which a sample could be obtained. Each sample received an identification number. Concurrently, the survey obtained from the same home received the same identification number for future analysis.

3.5. Ethical Approval. The study was approved by the VCU IRB, Office of Research Subjects Protection; the approval number was HM14199.

Prior to the June trip, physician leaders of the brigade met with both the local Ministry of Health and local community leaders to discuss the plans for the clinical and research aspects of the year's trip. The goals of this trip were to prioritize a formal assessment of the previously implemented water filter program, to assess new concerns of local leaders, and to provide local leaders with updates on prior years work.

4. Results

4.1. Population Characteristics. Sixty-five surveys were collected. Fifty-seven percent ($n = 37$) came from La Hicaca, and forty-three percent ($n = 28$) came from other villages visiting the clinic. Twelve home villages were reported. Table 1 lists the distribution of surveys by village.

4.2. Access to Clean Water and Water Sources. Eighty percent ($n = 52$) of individuals surveyed stated that they had access to clean water, while twenty percent ($n = 13$) did not. One hundred percent of respondents from La Hicaca ($n = 37$) indicated that they had access to clean water compared to 54% ($n = 15$), $P < 0.0001$, of respondents from the surrounding villages. Respondents reported use of a variety of different primary drinking water sources, summarized in Table 2. Twenty-five percent ($n = 16$) of all respondents used a public faucet as their main water source, 46% ($n = 30$) used a private faucet, 11% ($n = 7$) used a well, 6% ($n = 4$) used a river or stream directly, and 12% ($n = 8$) used another source as their main water source.

The results of survey questions examining water sources are summarized in Table 2. Comparisons between La Hicaca and the other villages are also provided.

Table 1: Distribution of surveys by village.

Village	Number of surveys
Agua Caliente	2
Agua Sarca	3
El Chorro	3
El Urraco	2
La Culata	3
La Esperanza	3
La Florida	4
La Hicaca	37
La Vega	1
Lomitas	2
San Felix	1
Santa Maria	4

Thirty-seven (57%) of the surveys were from La Hicaca and 28 (43%) were from surrounding villages.

4.3. Water Obtainment and Storage. Ninety-five percent ($n = 62$) of respondents obtained their water on foot and 5% ($n = 3$) "were not sure" which method of transportation they used to obtain water. The types of containers utilized for both water transportation and water storage in the home were assessed, the use of a lid to cover containers, methods of cleaning water containers, and hand hygiene (washing with soap and water) prior to cleaning containers.

Ninety-one percent ($n = 59$) used a plastic container to store water in their home, 5% ($n = 3$) used a glass container, and 5% ($n = 3$) were not sure about the make of the container for water storage. Table 2 lists responses to questions regarding water obtainment and storage.

4.4. Water Treatment. Sixty-nine percent ($n = 45$) of all survey respondents used a filter to clean their water. All of these individuals received filters from the HOMBRE medical team except for one, which had a filter from an unknown source.

A comparison of water treatment methods between La Hicaca and the surrounding villages is summarized in Table 2. Differences existed between these groups regarding the methods of water treatment employed. There was one respondent from a surrounding village who indicated filter use but not if it was used exclusively or in conjunction with another treatment method.

Data was collected on the use of other forms of water treatment including boiling of water, use of bottled water, and use of chlorine tablets. These methods were not used at a frequency similar to that of water filters.

4.5. Microbiologic Testing of Water Filters. Of the thirty-seven homes surveyed in La Hicaca, thirty-three water filter samples were obtained and paired with the survey of an individual living in the same home. At the time of collection, the year the family received the filter was recorded. Eleven of the sampled filters were from 2010, fourteen from 2011, one from 2012 (from a home that did not receive a filter in 2010), and seven from an unknown year. These results are listed in

Table 2: Results.

Self-reported sources of water			
	All respondents	La Hicaca	Surrounding villages
Public faucet	16/65 (25%)	15/37 (41%)	1/28 (4%)
Private faucet	30/65 (46%)	22/37 (60%)	8/28 (29%)
Well	7/65 (11%)	0	7/28 (25%)
River/stream	4/65 (6%)	0	4/28 (14%)
Other	8/65 (12%)	0	8/28 (29%)
Water obtainment and storage, all respondents % (*N*)			
Use of plastic container for water transport			60/65 (92%)
Use of plastic container for water storage			59/65 (91%)
Clean water transport container with soap and water			58/65 (89%)
Clean water storage container with soap and water			59/65 (91%)
Wash hands with soap and water before filling water containers			59/65 (91%)
Use lid for containers for water transport and storage			41/65 (63%)
Use lid for containers for water transport only			1/65 (2%)
Use lid for containers for water storage only			12/65 (19%)
Do not use a lid for water transport or storage			10/65 (15%)
Employed methods of water treatment, % (*N*)			
		La Hicaca	Other villages
Water filter only		17/37 (46%)	1/28 (3.5%)
Other methods only		0	8/28 (28.5%)
Water filter and other methods		19/37 (51%)	7/28 (25%)
None		1/37 (3%)	12/28 (43%)

Table 3: Mean bacterial colony count (CFU/100 mL) by bacterial type and year of filter distribution.

Year of filter distribution (number of samples)	Colony type and mean number CFU/100 mL			
	Enterobacter/ Citrobacter/Klebsiella (SD)	*Proteus/ Salmonella* (SD)	*E. coli* (SD)	Noncoliform bacteria (SD)
2012 (5)	0	256.2 (572.3)	0	0
2011 (14)	765.7 (2183.2)	552.9 (1124.5)	140 (495.8)	0
2010 (11)	3434.5 (3763.9)	1734.5 (1845.6)	16.4 (29.4)	120 (311.8)

The number of colony forming units was obtained by counting the number of colonies of each type on the sample plate. This was converted into number of CFU/100 mL dividing 100 by the number of mL of the sample (5 mL) and multiplying that number by the number of colonies counted on the plate.

Table 3 and demonstrate low numbers of *E. coli* present in the water filter samples.

4.6. Gastrointestinal Disease and Water Filter Use. Collectively, fifteen surveyed homes reported diarrhea beginning in the 30 days prior to survey collection; five reports were from La Hicaca and eleven were from other villages ($P < 0.01$).

There was an overall difference in the self-reported incidence of diarrhea between individuals using a filter and those not using a filter ($P < 0.01$). Five of the forty-five respondents using a filter reported diarrhea in their home within the last 30 days (11%), compared to eight of twenty not using a filter (40%). When analyzed by geographic site in either La Hicaca or in the surrounding villages, no difference was observed in self-reported diarrheal illness in homes with and without water filter use (Table 4).

Table 4: Filter use and diarrheal illness in La Hicaca and surrounding villages.

	La Hicaca		Surrounding villages	
	Diarrhea	No diarrhea	Diarrhea	No diarrhea
Filter	4	32	3	6
No filter	1	0	8	11
Total	5	32	11	17

The mean number of CFU was also compared between homes in La Hicaca with diarrheal illness and homes with no diarrheal illness. The homes in which no individuals reported diarrheal illness within the past 30 days had a mean CFU of 2954.9, compared to a mean CFU of 6400 in homes reporting recent diarrhea.

5. Discussion

Public health interventions to improve clean drinking water access are a priority for the medical relief trips of HOMBRE as well as the Global Health and Health Disparities Program of the VCU Medical Center. The water filter program began in 2008 and to date over 240 filters have been distributed in the region.

Access to clean water, the use of water filters, and the use of other water treatment methods differed within these geographically proximal communities. Individuals living in La Hicaca demonstrated a higher percentage of respondents with consistent access to a clean water source and a greater use of water filters. The self-reported incidence of diarrheal illness was lower in La Hicaca than in the surrounding villages.

While this water filter project has expanded to include villages surrounding La Hicaca, there may be additional barriers to access to potable water. Previous research suggests that distance is not the sole barrier to healthcare and access to clean water [15].

Topography and a lack of modern roads may limit the ability of villagers to travel by foot to the HOMBRE clinic and water filter distribution sites. For some, the travel time by foot was between 1 and 5 hours, in hot, summer weather. Individuals in La Hicaca have several resource advantages such as a functional dirt road as well as a small public health outpost. Although the region is impoverished, with no plumbing or electricity, compared to the surrounding villages, La Hicaca has a lower burden of poverty. This may consequently result in a heightened ability to obtain filters or employ other water treatment methods (Personal Communication, Olanchito Ministry of Health).

After testing water samples obtained from the filters, eighty-five percent revealed the presence of some bacterial growth. However, of the twenty-eight plates exhibiting bacterial growth, only six were positive for 40-1860 CFU/100 mL of *E. coli*. Enterotoxigenic *E. coli* (ETEC) strains are the principal etiologic pathogens of watery diarrhea and childhood diarrhea in the developing world [16]. ETEC accounts for more than 200 million causes of diarrhea [17].

Low counts of *E. coli* were recorded in the water samples. For water filters distributed in 2010 and 2011, the mean *E. coli* bacterial counts were 16.4 CFU/mL and 140 CFU/mL, respectively. Despite low level recovery of *E. coli* from a minority of filters, these households also did not report diarrheal illness. These data further suggest that clay water filters are microbiologically efficacious for the reduction of *E. coli,* as previously reported [18].

The low frequency of self-reported diarrhea in the study population may be the result of several factors. Studies on the pathogenesis of ETEC suggest that a dose of 10^4–10^{10} bacteria is necessary to cause infection [19]. WHO risk categories for *E. coli* in drinking water are 0/100 mL (compliance), 1–10/100 mL (low risk), 11–100/100 mL (intermediate risk), and 101–1000/100 mL (high risk). Of the six water samples positive for *E. coli*, four were intermediate and two were high risk by WHO risk category. Thus, household based clay water filters may sufficiently reduce microbial burden of enteric pathogens to levels below infectious inoculation.

Enterobacter/Citrobacter/Klebsiella colonies were detected in twenty-two samples, while *Proteus/Salmonella* (nontyphoidal) colonies were detected in twenty samples. *Klebsiella* species in drinking water are generally not enteric pathogens and are unlikely to pose health problems [20]. Similarly, nontyphoidal *Salmonella* species rarely cause waterborne diarrheal outbreaks [20]. It is postulated that their presence may be due in part to inconsistent cleaning of the filters and by environmental contamination. Of the homes undergoing water sampling, only two reported diarrhea in the past thirty days. Neither of these samples cultured positive for *E. coli*. This suggests that the diarrheal infections, if bacterial in origin and water borne, were from a source other than the water filters.

Although the majority of survey respondents lacked direct, piped water to their homes and used a large plastic container for water collection and storage, the questionnaire survey analysis revealed several important trends. First, although La Hicaca and the surrounding villages are geographically proximal and fall under the auspices of the same local Health Ministry, significant differences exist in water use, treatment practices, and self-reported diarrheal incidence. Ninety-seven percent of respondents in La Hicaca consistently used a household-based clay water filter, while only thirty-two percent of respondents from the other villages used a filter. Forty-three percent of respondents from the surrounding villages did not use any method of water treatment. While no respondents from La Hicaca indicated that their main source of drinking water was a river or stream, fourteen percent of respondents from the proximal villages obtained water from a local river. The high percentage of self-reported filter use in La Hicaca suggests that water filter use is a sustainable endeavor.

This study has several strengths. This study to the authors' knowledge is the first to assess the efficacy of household-based clay water filters, on site, in a Central American community. All interviews were performed as structured questionnaires by a trained interviewer limiting bias. Standardized methodology for water sampling and for field bacteriologic assessment of water was employed. Sample size was small and may not be representative of all households in the geographic catchment area. Exclusive use of household-based clay water filters for treatment cannot be confirmed. The heterogeneity in water storage containers and methods may have led to disparities in microbial contamination. Additional limitations include the absence of paired individual level data on diarrheal illness and confirmation of exclusive water filter use by respondents. For respondents using multiple sources of water treatment, it cannot be excluded that another source was used more frequently than the water filter. All of these factors may have impacted the self-reported incidence of diarrheal illness.

This study adds to the body of literature on water filtration systems for potable water in resource poor settings, particularly in Central America. Even within proximal, resource-poor communities, access to potable water varies. In addition, the data suggest that while home-based clay filters may not be completely efficacious in removing bacterial contaminants from drinking water, they may sufficiently reduce coliform

bacterial counts to levels below infectious inoculation. Further, for households with home-based clay water filters, self-reported use of the filters was high, suggesting that these water filtration systems may impact diarrheal illness. Thus, simple, inexpensive clay filters may be a sustainable and reliable public health intervention in resource limited settings lacking potable water. Consequently, their use should continue to expand in developing countries as a means to reduce gastrointestinal illness until more permanent solutions are successfully and consistently implemented.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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References

[1] J. M. Brown, S. Proum, and M. D. Sobsey, "*Escherichia coli* in household drinking water and diarrheal disease risk: evidence from Cambodia," *Water Science and Technology*, vol. 58, no. 4, pp. 757–763, 2008.

[2] D. M. Johnson, D. R. Hokanson, Q. Zhang, K. D. Czupinski, and J. Tang, "Feasibility of water purification technology in rural areas of developing countries," *Journal of Environmental Management*, vol. 88, no. 3, pp. 416–427, 2008.

[3] Water for People. Our Work: Honduras, http://www.waterforpeople.org/programs/central-america/honduras.html.

[4] G. Fink, I. Günther, and K. Hill, "The effect of water and sanitation on child health: evidence from the demographic and health surveys 1986–2007," *International Journal of Epidemiology*, vol. 40, no. 5, pp. 1196–1204, 2011.

[5] World Health Organization, *World Health Statistics 2012*, World Health Organization, Geneva, Switzerland, 2012.

[6] V. A. Oyanedel-Craver and J. A. Smith, "Sustainable colloidal-silver-impregnated ceramic filter for point-of-use water treatment," *Environmental Science and Technology*, vol. 42, no. 3, pp. 927–933, 2008.

[7] M. D. Sobsey, *Managing Water in the Home: Accelerated Health Gains from Improved Water Supply*, WHO, Geneva, Switzerland, 2002.

[8] T. F. Clasen, J. Brown, S. Collin, O. Suntura, and S. Cairncross, "Reducing diarrhea through the use of household-based ceramic water filters: a randomized, controlled trial in rural Bolivia," *The American Journal of Tropical Medicine and Hygiene*, vol. 70, no. 6, pp. 651–657, 2004.

[9] T. Clasen, W.-P. Schmidt, T. Rabie, I. Roberts, and S. Cairncross, "Interventions to improve water quality for preventing diarrhoea: systematic review and meta-analysis," *British Medical Journal*, vol. 334, no. 7597, pp. 782–785, 2007.

[10] La Hicaca, Northern Honduras. Map. N.d. La Hicaca, Honduras Weather Forecast. Web. February 2014.

[11] R. Hemrajani, B. Morehouse, K. Elam et al., "Top health concerns in rural Honduras following the introduction of clay water filters," *International Journal of Infectious Diseases*, vol. 14, no. 1, article e66, 2010.

[12] G. Halder, G. Bearman, K. Sanogo, and M. P. Stevens, "Water sanitation, access, use and self-reported diarrheal disease in rural Honduras," *Journal of Rural and Remote Health*, vol. 13, no. 2413, 2013.

[13] T. F. Clasen, J. Brown, and S. M. Collin, "Preventing diarrhoea with household ceramic water filters: assessment of a pilot project in Bolivia," *International Journal of Environmental Health Research*, vol. 16, no. 3, pp. 231–239, 2006.

[14] *Detection of Waterborne Coliforms and Fecal Coliforms with Coliscan Easygel*, http://bellehavenwatershed.wikispaces.com/file/detail/Coliform+Bacteria+Instructions.pdf.

[15] C. A. Pearson, M. P. Stevens, K. Sanogo, and G. Bearman, "Access and barriers to healthcare vary among three neighboring communities in northern Honduras," *International Journal of Family Medicine*, vol. 2012, Article ID 298472, 6 pages, 2012.

[16] J. B. Kaper, J. P. Nataro, and H. L. T. Mobley, "Pathogenic *Escherichia coli*," *Nature Reviews Microbiology*, vol. 2, no. 2, pp. 123–140, 2004.

[17] M. Tauschek, R. J. Gorrell, R. A. Strugnell, and R. M. Robins-Browne, "Identification of a protein secretory pathway for the secretion of heat-labile enterotoxin by an enterotoxigenic strain of *Escherichia coli*," *Proceedings of the National Academy of Sciences of the United States of America*, vol. 99, no. 10, pp. 7066–7071, 2002.

[18] J. Brown and M. Sobesy, *Use of Ceramic Water Filters in Cambodia*, Water and Sanitation Program. UNICEF, 2007.

[19] H. L. DuPont, S. B. Formal, R. B. Hornick et al., "Pathogenesis of *Escherichia coli* diarrhea," *The New England Journal of Medicine*, vol. 285, no. 1, pp. 1–9, 1971.

[20] World Health Organization, *Microbial Fact Sheets*, http://www.who.int/water_sanitation_health/dwq/gdwq3_11.pdf.