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# Reduced Diarrhea Prevalence and Improvements in Handwashing with Soap and Stored Drinking Water Quality Associated with Diarrheal Disease Awareness Measured by Interactive Voice Response Messages in the CHoBI7 Mobile Health Program

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*Abstract.* The Cholera-Hospital-Based-Intervention-for-7-Days (CHoBI7) mobile health program promotes water, sanitation, and hygiene (WASH) behaviors through interactive voice response (IVR), voice, and text messages to reduce diarrheal diseases in Bangladesh. The objective of this study was to investigate the relationship between responses to CHoBI7 WASH IVR quiz messages and subsequent diarrhea and WASH behaviors. Fourteen CHoBI7 IVR quiz messages on handwashing with soap and treatment of stored water were sent to 517 households with 1,777 participants during the 12-month program period. IVR message responses were classified as correct answer, incorrect answer, no response (did not press 1 or 2), and failed (did not answer the phone). Diarrhea prevalence was assessed through self-reported monthly clinical surveillance visits. Handwashing with soap was assessed by a 5-hour structured observation, and stored water quality was defined by *Escherichia coli* concentration. Households that responded correctly to a CHoBI7 IVR quiz message had significantly lower odds of diarrhea for all age groups (adults and children) at the subsequent visit 1 month later (odds ratio [OR], 0.73; 95% CI, 0.54–0.98), and significantly greater odds of handwashing with soap after stool-related events (OR, 2.48; 95% CI, 1.12–5.49) and *E. coli* levels $<$ 100 colony forming units (CFU)/100 mL (World Health Organization high-risk cutoff) in the stored household water (OR, 2.04; 95% CI, 1.25–3.33) compared with households that did not answer CHoBI7 IVR quiz calls. Correct responses to CHoBI7 IVR quizzes were associated with decreased diarrhea prevalence and improved stored drinking water quality and handwashing with soap behaviors at the subsequent visits. These findings suggest engagement in the CHoBI7 mobile health (mHealth) program and awareness of diarrheal disease prevention can reduce diarrhea and facilitate changes in WASH behaviors.

## INTRODUCTION

Diarrheal disease is a leading cause of death for children younger than 5 years globally, resulting in 500,000 deaths annually among children in this age group.[1,2] Water, sanitation, and hygiene (WASH) interventions such as improved sanitation, water sources, and drinking water treatment play an important role in reducing diarrheal diseases through interrupting fecal oral transmission routes.[3,4] Furthermore, handwashing with soap at key times is important for reducing enteric pathogen transmission.[5] However, encouraging households to sustain these practices over time has proved challenging.[6–9] Innovative approaches are needed to encourage sustained WASH behaviors.

Mobile health (mHealth)–based interventions have been shown to reduce disease and to increase protective health behaviors.[10–12] A systematic review[13] of mHealth studies found 15 randomized controlled trials (RCTs) of mHealth interventions that showed statistically significant improvement on health-protecting behaviors, and 16 RCTs showed statistically significant improvements on clinical outcomes. However, the majority of these published mHealth studies were conducted in high-income countries. In addition, mHealth studies conducted in low- and middle-income countries (LMICs) often focus on noncommunicable diseases, HIV/AIDS, or disease surveillance, not the promotion of interventions for communicable diseases such as diarrheal diseases.[14–16] Furthermore, there are only a handful of studies[17–19] published on WASH mHealth programs. One study conducted in India[17] reported increased handwashing with soap among mothers of young children after a 4- and 8-week mHealth program during which text messages were used as reminders to practice the target WASH behaviors. Another study[18] among youth in Tanzania aimed to promote handwashing with soap through the use of text messages and found modest increases in handwashing with soap behaviors. Evidence is needed on the impact of WASH mHealth programs globally.

During the past 10 years, mobile phone ownership and access have doubled globally, increasing the potential for mHealth interventions in low-resource settings.[20,21] In Bangladesh, mobile phone subscriptions included more than 176 million registered phone numbers in 2021, according to the Bangladesh Telecommunication Regulatory Commission.[22] Therefore, Bangladesh is an ideal environment for the use of mobile phones to promote key WASH behaviors to a large number of individuals at a low cost.

The Cholera-Hospital-Based Intervention-for-7-Days (CHoBI7) mHealth program was developed to reduce diarrheal diseases in Bangladesh.[23] Household members of patients with diarrhea are at a much higher risk of developing diarrheal diseases during the 7 days after being admitted to a health facility for diarrhea than the general population (100 times higher for cholera).[24–26] The CHoBI7 mHealth program promotes handwashing with soap, safe water storage, and water treatment in households with patients with diarrhea, and is delivered through a heath facility visit and weekly WASH-related voice and text messages for 12 months. The RCT of the CHoBI7 mHealth program found this program to be effective in increasing WASH behaviors and significantly reducing diarrheal disease and stunting in young children.[27]

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In this study, we investigated the association between interactive voice response (IVR) quiz message responses and subsequent handwashing with soap, stored drinking water quality, and diarrhea prevalence among participants in the CHoBI7 mHealth program. Our objective was to determine whether participant engagement with the CHoBI7 program measured through their IVR responses to program mHealth messages was associated with WASH behaviors and diarrheal disease prevalence.

## METHODS

This study was nested within the RCT of the CHoBI7 mHealth program, which was conducted from December 2016 to April 2019 in urban slums of Dhaka, Bangladesh. Patients with diarrhea presenting with three or more loose stools over a 24-hour period were recruited from two hospitals: the International Center for Diarrheal Disease Research, Bangladesh (icddr,b) Dhaka Hospital (a private hospital) and the Mugda General Hospital (a government hospital). To be eligible for participation, patients with diarrhea had to: 1) have had three or more loose stools during the past 24 hours, 2) plan to reside in Dhaka for the next 12 months, 3) have no basin for running water in the home (mostly slum areas of Dhaka), 4) have a child younger than 5 years in the household who produced a stool sample at baseline (used to determine the etiology of diarrhea), and 5) had to have a working mobile phone in the household. After recruitment of the patient with diarrhea, household members of the patients were enrolled, with a cluster being a patient with diarrhea and their corresponding household members.

Households with a patient with diarrhea were randomized to three study arms. The standard message arm received the standard recommendation given to patients with diarrhea at discharge on the use of oral rehydration solution to treat dehydration and did not receive mHealth messages from our program. The first CHoBI7 mHealth arm received a single in-person visit at a health facility during the time of illness for the patient with diarrhea in the household for delivery of the program and subsequent WASH mHealth messaging weekly for 12 months (mHealth with no home visits). The second CHoBI7 mHealth arm had this same intervention plus two home visits during the 7-day high-risk period after the patient with diarrhea was admitted to the health facility (mHealth with two home visits). Households with a patient with diarrhea in the CHoBI7 mHealth arms received weekly IVR, voice, and text messages from the CHoBI7 mHealth program over a 12-month period.[28] A complete description of the CHoBI7 mHealth intervention methodology is published elsewhere.[27,29]

CHoBI7 mHealth messaging in both intervention arms targeted five key behaviors: 1) preparation of soapy water (a low-cost alternative to bar soap made with water and detergent powder), 2) handwashing with soap at stool and food events, 3) treatment of household drinking water with chlorine tablets, 4) safe storage of drinking water in a water vessel with lid and tap, and 5) boiling drinking water before use. All messages were sent by a character named Dr. Chobi, a doctor at a hospital who calls and texts participants about the promoted WASH behaviors.[29] As a part of the CHoBI7 mHealth program, households were sent IVR quiz questions related to the WASH content of the program (e.g., IVR Quiz Day 3: "How long after adding a chlorine tablet should you wait to drink this water? Press 1 or 2," with 1 being the correct answer [30 minutes] and 2 being the incorrect answer [15 minutes]). The correct answer varied between 1 and 2 during the study period.

During the 12-month study, 14 IVR quiz questions were sent to each program household using the VIAMO platform (www.viamo.io) (Supplemental Table 1, adapted from Table 3 of the process evaluation of the CHoBI7 program).[28] This platform provided call log data that tracked IVR message and the corresponding responses. More details on the delivery of the CHoBI7 mHealth program are included elsewhere.[28]

Participant- or caregiver-reported diarrheal disease surveillance was conducted monthly for each household member during the 12-month study period. An episode of diarrhea was defined as three or more loose stools in a 24-hour period during the past 2 weeks. Five-hour structured observations were conducted at day 7, and 1, 3, 6, 9, and 12 months after enrollment for 50 randomly selected households in each study arm between 7:30 AM to 12:30 PM to observe handwashing practices during stool- and food-related events. Handwashing with soap was observed at the following key events: 1) after using the toilet, 2) after cleaning a child's anus, 3) after removing a child's feces, 4) before eating, 5) before feeding a child, and 6) before preparing food. Soap was defined as bar soap, soapy water, hand sanitizer, and liquid soap. In addition to the structured observations, research staff also conducted unannounced monthly spot check visits at 150 randomly selected households in each study arm at day 7, and 3, 6, 9, and 12 months after enrollment to assess household drinking water quality. The household's stored drinking water was tested for the presence of *Escherichia coli* by bacterial culture.[30] The following cutoffs defined by the World Health Organization (WHO) for drinking water quality were used for water *E. coli* counts: 1) $<$ 1 colony forming unit (CFU)/100 mL of *E. coli*, and 2) $<$ 100 CFU/100 mL of *E. coli*.[31] No compensation was provided for structured observations or spot checks. These activities were explained in our consent form.

**Statistical analysis.** We hypothesized the following relationships between IVR quiz responses and health and WASH outcomes over the 12-month study: 1) correct IVR quiz responses would be associated with reduced diarrhea prevalence, 2) correct IVR quiz responses would be associated with increased handwashing with soap as assessed by structured observation, and 3) correct IVR quiz responses would be associated with reduced *E. coli* concentrations in household stored drinking water. We analyzed diarrhea prevalence and all WASH outcomes in the subsequent month after the IVR quiz message was sent. The IVR quiz message responses were classified as correct, incorrect, no response (if the participant answered the call but did not press 1 or 2 as their response), and failed (if the participant did not answer the phone). There was no charge for responding to the IVR quizzes.

There were no significant differences in sociodemographic variables observed among study arms.[27] However, because of the potential for a relationship between caregiver educational level and both IVR quiz responses and WASH behaviors, we adjusted for education of the primary caregiver (any formal educations versus no formal education) in all statistical comparisons. CHoBI7 mHealth arms were combined for

this analysis because no significant differences were observed in responses to IVR questions by study arm.[28] Study hypotheses were tested using logistic regression with generalized estimating equations to account for clustering among participants in the same household. In these models, CHoBI7 mHealth program IVR quiz responses were the predictor, and diarrhea prevalence in the past 2 weeks (all participants, and participants younger than 5 and 2 years), handwashing with soap at key food and stool events, and household drinking water quality at the household visit the following month were the outcomes. The *E. coli* concentrations were categorized as *E. coli* $<$ 1 CFU/100 mL and *E. coli* $<$ 100 CFU/100 mL. All analyses were performed using STATA software version 13 (Stata Corp., Collect Station, TX).

## RESULTS

A total of 517 households were enrolled in the CHoBI7 mHealth program. Of these households, 264 were in the mHealth-with-no-home-visits arm and 253 households were in the mHealth-with-two-home-visits arm. In total, 1,777 participants were enrolled, 886 in the mHealth-with-no-home-visits arm and 891 in the mHealth-with-two-home-visits arm. The average age for program participants was 18 years (SD, 15 years; range, 0.08–80 years), with 33% of the participants (591 of 1,777) being younger than 5 years and 25% (441 of 1,777) being younger than 2 years (Table 1). Fifty-four percent of all participants (966 of 1,777) were female. Ninety-four percent of households (487 of 517) had at least one person who could read and write, 44% percent of households (230 of 517) reported refrigerator ownership, and 28% (146 of 517) reported having a concrete roof. Additional demographic information from this cohort is published in the process evaluation of the CHoBI7 mHealth program.[28]

TABLE 1
Baseline demographics for households participating in the Cholera-Hospital-Based-Intervention-for-7-Days (CHoBI7) Mobile Health Program

| Demographic | CHoBI7 Mobile health with no home visit arm | CHoBI7 Mobile health with two home visits arm |
|---|---|---|
| Study households, *n* | 264 | 253 |
| Study participants, in | 886 | 891 |
| Baseline household member age, years; mean ± SD (min–max) | 18 ± 15 (0.08–80) | 18 ± 15 (0.08–75) |
| 0–2 years, % | 24 | 25 |
| 2–5 years, % | 10 | 7 |
| 5–18 years, % | 11 | 12 |
| 18 years and greater, % | 55 | 56 |
| Female, % | 55 | 56 |
| Household roof type, % | | |
| Concrete | 28 | 28 |
| Other | 72 | 72 |
| Household wall type, % | | |
| Concrete | 70 | 71 |
| Other | 30 | 29 |
| Household floor type | | |
| Concrete | 97 | 96 |
| Other | 3 | 4 |
| Electricity, % | 93 | 92 |
| Refrigerator ownership, % | 45 | 44 |
| At least one household member can read and write, % | 95 | 94 |

max = maximum; min = minimum; SD = standard deviation.

Overall, 93% of households (482 of 517) answered more than 80% of IVR messages sent and 69% of households (358 of 517) answered all IVR quiz messages sent. A total of 6,652 IVR quiz messages were sent to program households. Eighty-nine percent of IVR quiz messages (5,906 of 6,652) sent to program households were received. Program households replied to 68% of unique IVR quiz messages received (4,004 of 5,906) and 81% of these IVR quiz responses (3,258 of 4,004) were correct.

The diarrhea prevalence over the 12-month study period for participants of all age groups was 9% (767 surveillance visits with reported diarrhea in the past 2 week out of 8,727 surveillance visits total), 16% (537 of 3,368) for children younger than 5 years, and 18% (416 of 2,348) for children younger than 2 years. Fifty-two percent of participants (254 of 488) 2 years of age or older washed their hands with soap at a food or stool related event during structured observation visits during the 12-month program period. Thirty-five percent of households (159 of 450) had a stored drinking water sample with no *E. coli* during the surveillance period and 81% (365 of 450) had $<$ 100 CFU/100 mL of *E. coli*.

Households that responded correctly to a CHoBI7 mHealth program IVR quiz had a significantly lower odds of diarrhea for all age groups at the clinical surveillance visit the subsequent month (odds ratio [OR], 0.73; 95% CI, 0.54–0.98) compared with households that did not answer the IVR quiz (Table 2). This association was even stronger for children younger than 2 years old (OR, 0.61; 95% CI, 0.41–0.92). There was a significantly greater odds of handwashing with soap at stool-related events for participants in households that responded correctly to an IVR quiz compared with households that did not answer the IVR quiz (OR, 2.48; 95% CI, 1.12–5.49) (Table 3) at the household visit the subsequent month. Households that responded correctly to a program IVR quiz had significantly greater odds of *E. coli* levels $<$ 100 CFU/100 mL ($<$ 100 CFU/100 mL means that water quality was not in the WHO high-risk category[31] and was a favorable outcome) in household stored drinking water at the spot check visit the subsequent month (OR, 2.04; 95% CI, 1.25–3.33) compared with those households that did not answer the IVR quiz (Table 4). Answering a call for an IVR quiz message even if the household did not respond to the IVR quiz was associated with greater odds of *E. coli* levels $<$ 100 CFU/100 mL in the household stored water at the spot check visit the subsequent month (OR, 2.04; 95% CI, 1.22–3.40) compared with those households that did not answer the IVR quiz (Supplemental Table 4). No other associations were found between

TABLE 2
Association between a response to a interactive voice response quiz message and diarrhea prevalence at household visit the subsequent month

| | Correct answer for IVR message response (vs. did not answer) | | | |
|---|---|---|---|---|
| Age categories | *n* | *N* | % | OR (95% CI) |
| All ages | 5,007 | 8,727 | 57 | 0.73 (0.54–0.98)† |
| Children $<$ 5 years | 1,953 | 3,368 | 58 | 0.76 (0.52–1.10) |
| Children $<$ 2 years | 1,368 | 2,348 | 58 | 0.61 (0.41–0.92)† |

IVR = interactive voice response; OR = odds ratio.
CIs were estimated with generalized estimating equations accounting for multiple participants within the same household.
Models were adjusted for caregiver educational level.
† Significant at $P < 0.05$.

TABLE 3
Association between response to CHoBI7 interactive voice response quiz message and handwashing with soap at the household visit the subsequent month

| | Correct answer for IVR message response (vs. did not answer) | | | |
|---|---|---|---|---|
| Key event | *n* | *N* | % | OR (95% CI) |
| Any event | 2,115 | 3,481 | 59 | 1.51 (0.85–2.68) |
| Food event | 1,632 | 2,732 | 60 | 1.11 (0.51–2.39) |
| Stool event | 483 | 749 | 61 | 2.48 (1.12–5.49)† |

IVR = interactive voice response; OR = odds ratio.
CIs were estimated with generalized estimating equations accounting for participants within the same household.
Models were adjusted for caregiver educational level.
† Significant at $P < 0.05$.

responding to or receiving an IVR quiz call and diarrhea or WASH outcomes (Supplemental Tables 1–3).

## DISCUSSION

To our knowledge, this is the first study that has assessed the association between IVR quiz message responses and diarrhea and WASH outcomes. Most mHealth programs in LMICs use either text or voice messages, with only a few delivering IVR for their programs.[32] In our study, we investigated the association between IVR quiz responses and subsequent diarrhea prevalence, stored drinking water quality, and observed handwashing with soap in urban Dhaka, Bangladesh. Households responding correctly to CHoBI7 mHealth program IVR quiz responses had significantly greater stored drinking water quality and handwashing with soap, and lower diarrhea prevalence at the household visit the subsequent month. These findings indicate that greater WASH awareness as assessed by correct IVR quiz responses and engagement in the CHoBI7 program (through pressing 1 or 2 for IVR quiz questions) was associated with reduced diarrheal disease prevalence, improved stored drinking water quality, and higher hand washing with soap among households in the CHoBI7 mHealth program. This promising result also suggests that IVR quiz responses can be used as a process evaluation indicator to track household-level awareness of diarrheal disease prevention during WASH mHealth programs, allowing for the identification of areas for improvement for program delivery. Future studies are needed to evaluate the association between IVR quiz responses and WASH and health outcomes in other settings globally. This study demonstrates the value of using IVR quiz responses to engage beneficiaries in WASH mHealth program delivery.

TABLE 4
Association between response to CHoBI7 interactive voice response quiz message and household stored water with *Escherichia coli* at the household visit the subsequent month

| | Correct answer for IVR message response (vs. did not answer) | | | |
|---|---|---|---|---|
| *E. coli* counts | *n* | *N* | % | OR (95% CI) |
| < 1/100 mL CFU | 577 | 1,063 | 54 | 1.79 (0.87–3.70) |
| < 100/100 mL CFU | 577 | 1,063 | 54 | 2.04 (1.25–3.33)† |
| < 1,000/100 mL CFU | 577 | 1,063 | 54 | 1.10 (0.59–2.03) |

CFU = colony forming units; IVR = interactive voice response; OR = odds ratio.
CIs were estimated with generalized estimating equations accounting for participants within the same household. Models were adjusted for caregiver educational level.
† Significant at $P < 0.05$.

This study complements our previous studies in Bangladesh,[33,34] which have found that diarrheal disease awareness was associated with sustained WASH behavior changes. In our previous RCT[34] of the CHoBI7 program, which focused on households with cholera patients, baseline cholera awareness was a mediator of sustained handwashing with soap behavior observed at the 6- to 12-month follow-up. Most recently, in the current RCT of the CHoBI7 mHealth program,[33] diarrhea awareness was a significant mediator of the association between program delivery and observed handwashing with soap and stored drinking water quality at the 12-month follow-up. Furthermore, our finding that awareness of diarrhea prevention was associated with a decrease in diarrhea is consistent with previous studies from Tanzania, Kenya, and Ethiopia,[35–37] which showed an association between increased WASH awareness and lower prevalence of diarrheal disease. When responding to IVR messages, participants had to play an active role in demonstrating their knowledge, potentially reinforcing their understanding of diarrhea prevention and highlighting important actions to prevent diarrhea transmission for themselves and their household members. This is supported by a previous study,[38] which demonstrated that two-way text messaging (where participants responded to messages) in comparison to one-way text messaging was associated with improved medication adherence. In addition, in our pilot work[29] for our study, we found that households often read CHoBI7 IVR quiz messages together in the evenings to discuss the questions, which may also reinforce behavioral recommendations.

Households that responded incorrectly or did not respond at all to IVR quiz messages had no significant difference in diarrhea prevalence. This indicates that simply interacting with the program messages was not sufficient to change diarrhea prevalence, and that awareness about diarrhea prevention was important. Interestingly, we found that receiving IVR quiz messages, even when incorrect answers were given, or 1 or 2 was not pressed, was associated with improved stored water quality when compared with those households that did not answer IVR quiz messages. One potential explanation for this finding is that if households answered a question incorrectly, or did not press 1 or 2 in response to the question, a reply voice message explained the correct answer. This additional reinforcement may have helped participants engage with and understand the information provided, leading to improved stored water quality. However, we did not see this pattern with the handwashing with soap or diarrhea outcomes. We are not sure of the reason we saw an impact of the IVR quiz messages on < 100 CFU/100 mL but not for < 1 CFU/100 mL. This finding should be complemented by qualitative research to investigate further the role IVR quiz messages played in improving safe water storage, water treatment, and handwashing with soap behaviors.

This study has some limitations. First, we do not have information on whom in the household responded to the IVR quiz message. Future studies should collect this information. Second, although we have adjusted our estimates for attained education, there is the potential for confounding in the estimated associations from unmeasured variables, such as household income. Lastly, diarrhea prevalence was measured by self or caregiver report, which may be prone to reporting bias. Future studies should measure enteric pathogens in stool

for these study participants to investigate the impact of the IVR quiz messages on specific enteric infections.

This study has several strengths. First, the VIAMO mobile platform allowed us to track household responses to IVR quiz messages, and determine whether IVR messages were listened to completely. Second, stored drinking water samples were collected from randomly selected households using unannounced spot checks for *E. coli* analyses, which prevented participants from preparing for visits. Third, we conducted 5-hour structured observation data to assess handwashing with soap behavior rather than participant self-reported data. Fourth, the prospective design of the study allowed us to investigate how IVR quiz responses were associated with subsequent diarrhea prevalence and WASH outcomes.

In this study, we found that correct responses to CHoBI7 WASH mHealth program IVR quiz messages were associated with decreased diarrhea prevalence, improved stored drinking water quality, and higher handwashing with soap. These findings suggest that IVR quizzes present a promising approach to engage beneficiaries in WASH mHealth programs, which is particularly valuable now during the ongoing COVID-19 pandemic, when the ability to conduct in-person visits for intervention delivery is limited. Future WASH mHealth programs should consider using IVR as part of program delivery in LMIC settings globally.

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