

Diarrhoeal disease knowledge among diarrhoea patient households: findings from the randomised controlled trial of the Cholera-Hospital-Based-Intervention-for-7-days (CHoBI7) mobile health program

Jahed Masud¹, Md. Sazzadul Islam Bhuyian¹, Shwapon Kumar Biswas¹, Fatema Zohura¹, Jamie Perin², Nowshin Papri¹, Fahmida Dil Farzana¹, Tahmina Parvin¹, Shirajum Monira¹, Munirul Alam¹ and Christine Marie George PhD²

¹ International Centre for Diarrhoeal Disease Research, Bangladesh, Dhaka, Bangladesh

² Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, USA

Abstract

OBJECTIVE The objective of this study was to evaluate the impact of the Cholera-Hospital-Based-Intervention-for-7-days (CHoBI7) handwashing with soap and water treatment mobile health (mHealth) program on diarrhoeal disease knowledge among diarrhoea patients and their household members in urban Dhaka, Bangladesh.

METHODS A cluster-randomised controlled trial of the CHoBI7 mHealth program was conducted among diarrhoea patient households in Dhaka, Bangladesh. Patients were randomised to three arms: standard recommendation on oral rehydration solution use; health facility delivery of CHoBI7 plus mHealth (weekly voice and text messages) (no home visits); and health facility delivery of CHoBI7 plus two home visits and mHealth. An open-ended questionnaire was administered to 1468 participants 12 years of age or older on diarrhoeal disease transmission and prevention. These items were combined to form a diarrhoeal disease knowledge score measured at baseline and at a 1 week, 6 month and 12 month follow-up.

RESULTS At baseline, when participants were asked to report three ways diarrhoeal diseases were spread 37% (546/1468) of participants reported by water, 13% (187/1468) by lack of handwashing and 4% (53/1468) by food not being covered properly. At baseline when asked to name three ways diarrhoeal diseases could be prevented, 35% (515/1468) of participants reported safe water, and 16% (228/1468) reported handwashing with soap. At the 12-month follow-up, the overall diarrhoeal disease knowledge score was significantly higher in the mHealth with no home visits arm (score coefficient: 0.69, 95% Confidence Interval: 0.36, 1.01, $P < 0.0001$) and the mHealth with two home visits arm (score coefficient: 1.18, 95% CI: 0.87, 1.49, $P < 0.0001$) compared with the standard recommendation arm.

CONCLUSION The CHoBI7 mHealth program significantly increased knowledge of diarrhoeal disease transmission and prevention among diarrhoea patients and their household members 12 months after in-person visits for program delivery were conducted.

keywords handwashing, safe water, diarrhoeal disease knowledge, CHoBI7, Bangladesh, mobile health, randomised controlled trial

Sustainable Development Goals (SDGs): SDG 3 (good health and well-being), SDG 6 (clean water and sanitation), SDG 9 (industry, innovation and infrastructure), SDG 17 (partnerships for the goals)

Introduction

Diarrhoea is a leading cause of death in children under 5 years of age globally, causing an estimated 500,000 deaths annually [1]. In Bangladesh, children under 5 years of age are estimated to have 28 million diarrhoea episodes each year [2]. Frequent diarrhoea has been

associated with growth faltering [3–13]. Growth faltering in young children is associated with an increased risk of mortality and impaired cognitive development [14,15]. Previous studies have found that poor caregiver hand hygiene, lack of water treatment and lack of caregiver awareness of diarrhoeal disease prevention are risk factors for diarrhoeal disease among susceptible paediatric

populations [16–18]. Water, sanitation and hygiene (WASH) interventions have the potential to reduce diarrhoeal disease by an estimated 30% to 70% in children under five years of age globally [19].

Previous studies have shown that contextual, technological and psychosocial factors play an important role in WASH behaviour change and that knowledge alone is often not sufficient to facilitate WASH behaviour [20–25]. Nevertheless, knowledge of when and how to perform a WASH behaviour is also a crucial component to habitually performing and sustaining these behaviour over time [26]. In Nigeria, 50% of mothers thought that diarrhoea was caused by the angel of darkness while only 10% thought diarrhoea was caused by contaminated food [16]. This lack of diarrhoeal disease awareness among caregivers was associated with increased paediatric diarrhoeal disease. Another study in the Democratic Republic of the Congo found that lack of caregiver knowledge of safe disposal of child faeces and diarrhoeal disease transmission pathways was associated paediatric diarrhoea [17]. Consistent with these findings, a study in Bolivia found low knowledge of diarrhoeal diseases was associated with increased paediatric diarrhoea [27].

Previous studies have found that the household members of diarrhoea patients are at a much higher risk of developing diarrhoeal diseases (>100 for cholera) than the general population during the 7-day period after the diarrhoea patient in the household presents at a health facility for treatment [28–33]. However, despite this high risk, there are few interventions targeting this susceptible population, and little is known about their knowledge of diarrhoeal disease transmission and prevention. Our previous study conducted in Dhaka, Bangladesh found low knowledge of cholera transmission and prevention among cholera patient households, and that cholera knowledge was a significant mediator of handwashing with soap practices [26,34]. Studies are needed that investigate diarrhoeal disease knowledge among this high-risk population to allow for behaviour change communication programs tailored for diarrhoea patients and their household members.

The time patients and their caregivers spend at a health facility for treatment of diarrhoea presents an ideal opportunity to deliver WASH interventions when perceived severity of diarrhoeal diseases and benefits of water treatment and handwashing with soap are likely highest [35]. In an effort to develop a standard of care to reduce diarrhoea among household members of diarrhoea patients, our research group developed the Cholera-Hospital-Based-Intervention-for-7-days (CHoBI7) [36]. Chobi means ‘picture’ in Bangla for the pictorial modules delivered as part of the program. This WASH program

focuses on promoting handwashing with soap and water treatment to diarrhoea patients and their household members during the one-week period after the patient is admitted to the health facility, when their household is at highest risk for diarrhoeal diseases. Our previous randomised controlled trial (RCT) found that delivery of the CHoBI7 program to cholera patient households resulted in a 47% reduction in overall cholera infections, and a significant reduction in symptomatic cholera during the 1-week high-risk period after the presentation of the index patient [36]. Furthermore, the 7-day CHoBI7 program led to significant sustained improvements in household stored drinking water quality and observed handwashing with soap practices, and knowledge of cholera transmission and prevention 12-month post-intervention [37].

Building on this previous work, we are currently investigating strategies to scale this intervention across Bangladesh, through delivery of CHoBI7 as a mobile health (mHealth) program. Phone-based reminders are an emerging low-cost intervention to deliver public health programs that has been shown to lead to improved case management and disease prevention practices [38–43]. Delivery of public health programs through mHealth presents a scalable approach for which public health information can be sent to a large number of households at minimal cost and can serve as valuable cues to action to facilitate behaviour change. The objective of our study was to evaluate the impact of the CHoBI7 mHealth program on diarrhoeal disease knowledge among diarrhoea patients and their household members in urban Dhaka, Bangladesh.

Methods

Study design

This study was part of the RCT of the CHoBI7 mHealth program and was conducted from December 2016 to April 2019 [43]. Study participants were diarrhoea patients admitted to the International Centre for Diarrhoeal Disease Research, Bangladesh (icddr,b) and Mugda General Hospital and their household members. Diarrhoea patients were defined as patients having acute watery diarrhoea, defined as three or more loose stools in the past 24 hours. The RCT compared the standard recommendation given in Bangladesh to diarrhoea patients at hospital discharge on oral rehydration solution use for dehydration (standard recommendation arm) to the CHoBI7 mHealth program with either a single in-person visit for health facility delivery of the program and mHealth (mHealth with no home visits arm)

or health facility delivery of the program, mHealth and two home visits (mHealth with two home visits arm). To minimise bias, there were two separate teams for the intervention and evaluation activities. The trial is registered at ClinicalTrials.gov (NCT04008134). This analysis was an exploratory outcome.

Diarrhoea patients and household members over 12 years of age were administered an open-ended questionnaire tool at baseline and 1 week and 6 and 12 months after enrolment to assess knowledge of diarrhoeal disease transmission and prevention, and the key times for handwashing with soap promoted in the CHoBI7 mHealth program (before food and after stool-related events). Participants were asked: 'Can you name three important ways diarrhoea is spread?' (diarrhoeal disease transmission) (1 point for each correct response, a total possible score of 3 points); 'Can you name three important ways diarrhoea can be prevented?' (diarrhoeal disease prevention) (1 point for each correct response, a total possible score of 3 points); and 'Can you please name the 4 key times for handwashing with soap?' (key times for handwashing with soap) (1 point for each correct response, a total possible score of 4 points). These open-ended questions were coded. If more than 3 correct responses were given for diarrhoeal disease transmission or prevention, the maximum possible score remained 3 points. Similarly, if more than 4 correct responses for key times for handwashing with soap were given, the maximum possible score remained 4 points. This scoring system is based on the previous cholera awareness score we published in Saif-Ur-Rahman *et al* [34]. Correct responses for diarrhoeal disease transmission were as follows: (i) by faeces, (ii) after cleaning a child's faeces (iii) by consuming rotten or spoiled food, (iv) by not completely covering food, (v) by food that has germs or faeces, (vi) by not washing hands, (vii) by water, (viii) by flies, (ix) by not washing hands with soap, (x) by not washing hands with soap before eating, cooking food, cutting vegetables and feeding children, and (xi) by not washing hands with soap after using the toilet or defecation/urination. Correct responses for diarrhoeal disease prevention were as follows: (i) by eating clean food, (ii) by not eating street vended food, (iii) by covering food, (iv) by handwashing with soap at a stool- or food-related event, and (v) by drinking boiled or chlorinated water. Correct responses for the key times for handwashing with soap were: (i) after using the toilet, (ii) after cleaning a child's anus, (iii) after removing a child's faeces, (iv) before eating, (v) before feeding a child, (vi) before preparing food and (vii) before serving food. The overall diarrhoeal disease

knowledge score was calculated by summing the points for correct answers from all three questions. The total possible diarrhoeal disease knowledge score was 10 (range 0–10).

CHoBI7 WASH mHealth program

The CHoBI7 mHealth program was developed through a theory-driven approach informed by the Integrated Behavioral Model for Water, Sanitation and Hygiene and the Risks, Attitudes, Norms, Abilities and Self-regulation Model [44,45]. A detailed description of intervention development is published elsewhere [46]. The CHoBI7 mHealth program is initially delivered during a health facility visit by a health worker bedside to a diarrhoea patient and their accompanying household members during the time of illness. The health worker delivers the pictorial CHoBI7 WASH module on diarrhoeal disease transmission and prevention, and instructions on handwashing with soap at stool- and food-related events and water treatment. A diarrhoea prevention package containing the following items is also provided: a one-month supply of chlorine tablets for water treatment, one soapy water bottle (water and detergent powder), a handwashing station, and a water vessel with a lid and tap to ensure safe water storage. Households are instructed to boil their water once their supply of chlorine tablets is completed. After health facility delivery of the program, diarrhoea patient households receive weekly voice and text messages from the CHoBI7 mHealth program over a 12-month period. In the mHealth with two home visits arm, two 30-minute home visits by a health worker are conducted during the week after the index diarrhoea patient is recruited at the health facility to review the pictorial module.

Statistical analysis

To compare responses for knowledge on diarrhoeal disease transmission and prevention, and the key times for handwashing with soap between study arms chi-square tests were performed. *P*-values were calculated by comparing the sum of correct responses for each of these items. Linear regression was performed to compare the diarrhoeal disease knowledge score between study arms using generalised estimating equations to account for clustering within households and approximate 95% confidence intervals, where diarrhoeal disease knowledge score was the outcome and study arm was the predictor at each time point. Stata version 13 was used for all analyses.

Table 1 Reported diarrhoea transmission routes: Can you name three important ways diarrhoea is spread?

Diarrhoea transmission												
	Baseline (N = 1468)			1-week follow-up (N = 842)			6-month follow-up (N =715)			12-month follow-up (N =882)		
	Standard arm% (N = 462)	mHealth with no home visits % (N = 495)	mHealth with two home visits % (N = 511)	Standard arm % (N = 281)	mHealth with no home visits % (N = 267)	mHealth with two home visits % (N = 294)	Standard arm % (N = 223)	mHealth with no home visits % (N = 221)	mHealth with two home visits % (N = 271)	Standard arm % (N = 277)	mHealth with no home visits % (N = 285)	mHealth with two home visits % (N = 320)
Major themes												
Water	37 (173)	37 (182)	37 (191)	40 (111)	54 (144)	55 (161)	43 (95)	50 (111)	55 (148)	39 (107)	48 (138)	60 (191)
Spoiled/rotten food	38 (176)	34 (170)	40 (202)	45 (127)	21 (56)	23 (67)	44 (98)	29 (65)	28 (76)	43 (118)	35 (100)	31 (100)
Lack of handwashing	12 (54)	13 (62)	14 (71)	16 (45)	30 (79)	29 (84)	17 (39)	25 (55)	25 (69)	18 (49)	21 (61)	23 (73)
Food not covered	5 (21)	3 (16)	3 (16)	5 (15)	3 (9)	2 (5)	5 (10)	1 (3)	2 (6)	1 (4)	2 (7)	2 (6)
Dirty hands	6 (26)	5 (25)	10 (49)	4 (12)	6 (17)	6 (17)	8 (17)	7 (16)	8 (23)	4 (11)	7 (19)	5 (17)
Feces	3 (16)	5 (24)	2 (11)	8 (23)	16 (43)	21 (62)	11 (25)	12 (27)	17 (47)	14 (38)	14 (41)	22 (70)
Poor hygiene	36 (164)	36 (176)	31 (159)	46 (130)	21 (57)	22 (64)	35 (59)	22 (49)	19 (51)	28 (78)	23 (65)	23 (72)
Food eaten outside the home	5 (23)	7 (35)	5 (25)	6 (16)	2 (4)	3 (8)	3 (7)	5 (11)	3 (8)	6 (17)	7 (20)	6 (18)
Spicy food	0 (1)	1 (3)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)	0 (0)	0 (1)	0 (1)	0 (0)
Flies	5 (21)	3 (14)	4 (19)	5 (15)	1 (2)	1 (2)	2 (5)	0 (1)	1 (2)	4 (11)	1 (4)	1 (3)
Air	1 (3)	1 (4)	0 (1)	0 (1)	1 (2)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (1)	0 (0)
Unclean Environment	1 (6)	2 (11)	2 (11)	2 (6)	0 (1)	1 (3)	1 (3)	0 (0)	1 (3)	1 (4)	1 (3)	1 (2)

Table 2 Reported preventive measures for diarrhoea: Can you name three important ways diarrhoea can be prevented?

Diarrhoeal disease prevention	Baseline (N = 1468)			1-week follow-up (N = 842)			6-month follow-up (N = 715)			12-month follow-up (N = 882)		
	Standard arm % (N = 462)	mHealth with no home visits % (N = 495)	mHealth with two home visits % (N = 511)	Standard arm % (N = 281)	mHealth with no home visits % (N = 267)	mHealth with two home visits % (N = 294)	Standard arm % (N = 223)	mHealth with no home visits % (N = 221)	mHealth with two home visits % (N = 271)	Standard arm % (N = 277)	mHealth with no home visits % (N = 285)	mHealth with two home visits % (N = 320)
Major themes												
Safe water	35 (163)	34 (167)	36 (185)	40 (111)	54 (145)	53 (157)	40 (89)	52 (116)	55 (148)	39 (107)	54 (155)	58 (187)
Handwashing (soap mentioned)	15 (69)	16 (80)	15 (79)	22 (63)	41 (110)	47 (138)	20 (45)	39 (85)	37 (100)	26 (73)	36 (102)	51 (164)
Handwashing (no soap mentioned)	29 (133)	33 (163)	33 (170)	29 (81)	51 (136)	49 (143)	30 (66)	45 (100)	49 (133)	35 (98)	40 (115)	41 (131)
Covering food	7 (34)	5 (27)	6 (33)	9 (24)	3 (8)	2 (6)	8 (17)	3 (7)	2 (6)	5 (13)	3 (9)	3 (11)
Clean food	18 (82)	13 (64)	14 (71)	22 (62)	7 (19)	8 (23)	22 (48)	12 (26)	10 (27)	15 (42)	12 (34)	9 (28)
Not eating street vended food	1 (5)	1 (3)	0 (1)	1 (2)	1 (2)	0 (0)	0 (1)	0 (0)	1 (2)	0 (0)	0 (0)	0 (1)
Good hygiene	55 (254)	57 (281)	52 (268)	64 (179)	35 (93)	36 (105)	59 (132)	42 (92)	45 (123)	63 (175)	46 (130)	43 (137)

Ethical approvals

The study protocol was approved by the Ethical Review Committee at icddr,b and the Institutional Review Board of the Johns Hopkins Bloomberg School of Public.

Results

A total of 1468 individuals (diarrhoea patients and household members) from 769 households enrolled in the CHoBI7 study were administered the diarrhoeal disease knowledge questionnaire at baseline (495 mHealth with no home visits arm participants, 511 mHealth with two home visits arm participants and 462 standard recommendation arm participants). The mean age for participants (>12 years) was 29 years (range: 12–80) and 62% (912/1468) were female.

Baseline

At baseline, there were no significant differences in knowledge of diarrhoea transmission ($P = 0.50$) or prevention ($P = 0.65$) by study arm (Tables 1 and 2 and Table S1). Six percent (89/1468) of participants were able to correctly report three transmission routes for diarrhoea. Thirty seven percent (548/1468) of participants reported diarrhoea was spread by rotten/spoiled food, 37% (546/1468) by water, 13% (187/1468) by not handwashing and 4% (53/1468) by food not being covered properly (Table 1). One percent (14/1468) of participants were able to report correctly three ways to prevent diarrhoea at baseline (Table 2). Thirty five percent (515/1468) of participants reported safe water as a method to prevent diarrhoea, and 16% (228/1468) reported handwashing with soap. Two percent (25/1468) of participants at baseline were able to report four key times for handwashing with soap, and this did not significantly differ by study arm ($P = 0.28$) (Table 3). For key times for handwashing with soap, 87% (1282/1468) of participants reported handwashing with soap after using the toilet, 80% (1177/1468) before eating food, and 14% (209/1468) after touching dirty things. At baseline, 1% (8/1468) of participants reported diarrhoea was spread by air, and 0.3% (4/1468) reported diarrhoea was spread by spicy food. There was no significant difference for either finding by study arm. For the key times for handwashing with soap to prevent diarrhoea, at baseline 9% (132/1468) of participants reported handwashing with soap after eating, and 9% (134/1468) reported handwashing with soap after working. There was no significant difference by study arm for either of these findings. The overall diarrhoeal disease knowledge score was similar in the

mHealth with no home visits arm (mean score 4.1) (score coefficient: -0.06 95% Confidence Interval (CI): -0.28 , 0.15 , $P = 0.58$) and the mHealth with two home visits arm (mean score 4.1) (score coefficient: -0.06 , 95% CI: -0.27 , 0.16 , $P = 0.59$) compared with the standard recommendation arm (mean score 4.2).

One-week follow-up

The overall diarrhoeal disease knowledge score was significantly higher in the mHealth with no home visits arm (mean score 5.3) (score coefficient: 0.67 95% CI: 0.38 , 0.96 , $P < 0.0001$) and the mHealth with two home visits arm (mean score 5.4) (score coefficient: 0.78 , 95% CI: 0.49 , 1.07 , $P < 0.0001$) compared to the standard recommendation arm (mean score 4.7). There was no significant difference in the diarrhoeal disease knowledge scores between the mHealth with two home visits and the mHealth with no home visits arm ($P = 0.77$). Thirty percent (79/267) of mHealth with no home visits arm participants and 29% (84/294) of mHealth with two home visits arm participants reported diarrhoea was spread by lack of handwashing compared with 16% (45/281) in the standard recommendation arm ($P < 0.001$). Fifty four percent (144/267) of mHealth with no home visits arm participants and 55% (161/294) of mHealth with two home visits arm participants reported diarrhoea was spread by water vs. 40% (111/281) in the standard recommendation arm ($P < 0.001$). Fifty four percent (145/267) of mHealth with no home visits arm participants and 53% (157/294) of mHealth with two home visits arm participants reported diarrhoea can be prevented by safe water vs. 40% (111/281) in the standard recommendation arm ($P < 0.001$). Forty one percent (110/267) of mHealth with no home visits arm participants and 47% (138/294) of mHealth with two home visits arm participants reported diarrhoea can be prevented by handwashing with soap compared with 22% (63/281) in the standard recommendation arm ($P < 0.001$). Forty seven percent (125/267) of mHealth with no home visits arm participants and 43% (126/294) of mHealth with two home visits arm participants reported handwashing with soap before food preparation compared with 14% (38/281) in the standard recommendation arm ($P < 0.001$).

Six-month follow-up

The overall diarrhoeal disease knowledge score was significantly higher in the mHealth with no home visits arm (mean score 5.2) (score coefficient: 0.57 , 95% CI: 0.22 , 0.92 , $P = 0.001$) and the mHealth with two home visits arm (mean score 5.2) (score coefficient: 0.68 , 95% CI:

Table 3 Reported key times for handwashing with soap: Can you please name the four key times for handwashing with soap?

Key times for handwashing with soap																
	Baseline (N = 1468)				1-week follow-up (N = 842)				6-month follow-up (N = 715)				12-month follow-up (N = 882)			
	Standard arm% (N = 462)	mHealth with no home visits % (N = 495)	mHealth with two home visits % (N = 511)		Standard arm% (N = 281)	mHealth with no home visits % (N = 267)	mHealth with two home visits % (N = 294)		Standard arm% (N = 223)	mHealth with no home visits % (N = 221)	mHealth with two home visits % (N = 271)		Standard arm% (N = 277)	mHealth with no home visits % (N = 285)	mHealth with two home visits % (N = 320)	
Major themes																
After using the toilet	88 (405)	87 (432)	87 (445)		93 (260)	94 (252)	93 (272)		94 (209)	93 (203)	93 (252)		91 (253)	93 (264)	95 (303)	
Before eating food	79 (365)	81 (403)	80 (409)		80 (226)	86 (229)	86 (254)		79 (177)	86 (190)	86 (232)		78 (217)	88 (250)	90 (289)	
Before food preparation	14 (64)	15 (76)	16 (84)		14 (38)	47 (125)	43 (126)		20 (44)	43 (95)	41 (112)		21 (57)	40 (113)	36 (114)	
Before serving food	0 (2)	1 (5)	2 (8)		0 (1)	3 (8)	3 (8)		1 (2)	2 (4)	1 (3)		0 (0)	1 (2)	1 (3)	
After cleaning child's faeces	4 (18)	5 (26)	5 (26)		4 (11)	8 (21)	10 (28)		2 (5)	11 (25)	5 (13)		5 (13)	4 (12)	6 (18)	
After cleaning a child anus	5 (24)	5 (24)	4 (20)		4 (12)	10 (26)	13 (37)		7 (15)	11 (24)	14 (38)		8 (21)	13 (38)	22 (69)	
After eating	10 (48)	10 (48)	7 (36)		9 (25)	6 (16)	3 (8)		5 (11)	4 (9)	3 (7)		4 (12)	6 (17)	3 (11)	
After working	19 (44)	9 (43)	10 (51)		11 (30)	2 (6)	4 (12)		10 (23)	2 (5)	4 (12)		14 (40)	6 (16)	6 (20)	
After touching dirty things	16 (74)	12 (59)	15 (76)		16 (45)	4 (12)	2 (7)		17 (37)	3 (6)	6 (16)		17 (47)	5 (13)	7 (23)	
Before going to sleep	1 (4)	1 (5)	1 (4)		0 (1)	0 (0)	0 (0)		0 (1)	0 (0)	0 (1)		0 (1)	0 (0)	0 (0)	
Before feeding a child	9 (42)	8 (39)	8 (42)		8 (22)	9 (25)	13 (37)		9 (20)	9 (19)	10 (28)		4 (12)	7 (19)	7 (23)	

0.34, 1.01, $P < 0.0001$) compared to the standard recommendation arm (mean score 4.6). There was no significant difference observed in the diarrhoeal disease knowledge scores between the mHealth with two home visits and the mHealth with no home visits arm ($P = 0.52$). Twenty five percent (55/221) of mHealth with no home visits arm participants and 25% (69/271) of mHealth with two home visits arm participants reported diarrhoea was spread by lack of handwashing compared with 17% (39/223) in the standard recommendation arm ($P = 0.07$). Fifty percent (111/221) of mHealth with no home visits arm participants and 55% (148/271) of mHealth with two home visits arm participants reported diarrhoea was spread by water compared with 43% (95/223) in the standard recommendation arm ($P = 0.03$). Fifty three percent (116/221) of mHealth with no home visits arm participants and 55% (148/271) of mHealth with two home visits arm participants reported diarrhoea can be prevented by safe water compared with 40% (89/223) in the standard recommendation arm ($P = 0.003$). Thirty eight percent (85/221) of mHealth with no home visits arm participants and 37% (100/271) of mHealth with two home visits arm participants reported diarrhoea can be prevented by handwashing with soap compared with 20% (45/223) in the standard recommendation arm ($P < 0.001$). Forty three percent (95/221) of mHealth with no home visits arm participants and 41% (112/271) of mHealth with two home visits arm participants reported handwashing with soap before food preparation compared with 20% (44/223) in the standard recommendation arm ($P < 0.001$).

12-month follow-up

At the 12-month follow-up, the overall diarrhoeal disease knowledge score was significantly higher in the mHealth with no home visits arm (mean score 5.2) (score coefficient: 0.69, 95% CI: 0.36, 1.01, $P < 0.0001$) and the mHealth with two home visits arm (mean score 5.7) (score coefficient: 1.18, 95% CI: 0.87, 1.49, $P < 0.0001$) compared to the standard recommendation arm (mean score 4.6). The mHealth with two home visits arm participants had significantly higher diarrhoeal disease knowledge scores compared to the mHealth with no home visits arm participants ($P = 0.004$). Twenty one percent (61/285) of mHealth with no home visits arm participants and 23% (73/320) of mHealth with two home visits arm participants reported diarrhoea was spread by lack of handwashing vs. 18% (49/277) in the standard recommendation arm ($P = 0.29$). Forty eight percent (138/285) of mHealth with no home visits arm participants and 60% (191/320) of mHealth with two home

visits arm participants reported diarrhoea was spread by water vs. 39% (107/277) in the standard recommendation arm ($P < 0.001$). Fifty four percent (155/285) of mHealth with no home visits arm participants and 58% (187/320) of mHealth with two home visits arm participants reported diarrhoea can be prevented by safe water vs. 39% (107/277) in the standard recommendation arm ($P < 0.001$). Thirty six percent (102/285) of mHealth with no home visits arm participants and 51% (164/320) of mHealth with two home visits arm participants reported diarrhoea can be prevented by handwashing with soap compared to 26% (73/277) in the standard recommendation arm ($P < 0.001$). Forty percent (113/285) of mHealth with no home visits arm participants and 36% (114/320) of mHealth with two home visits arm participants reported handwashing with soap before food preparation compared with 21% (57/277) in the standard recommendation arm ($P < 0.001$).

Discussion

The CHoBI7 mHealth program led to significantly higher diarrhoeal disease knowledge 1 week, 6 months, and 12 months after in-person visits for program delivery were conducted. This result complements the health and behavioural outcomes from this RCT which showed that delivery of the CHoBI7 mHealth program significantly reduced diarrhoea and stunting among young children, and led to sustained handwashing with soap practices and improved household stored drinking water quality 12 months after enrolment [43]. This is the first RCT, to our knowledge, to evaluate the effectiveness of a WASH mHealth program in increasing diarrhoeal disease knowledge. These findings demonstrate that the CHoBI7 mHealth program presents a low-cost approach for WASH program delivery that can increase diarrhoeal disease knowledge and improve WASH behaviours and child health among a high-risk population for diarrhoeal diseases.

The CHoBI7 mHealth program was highly effective in increasing knowledge of handwashing with soap and safe drinking water as methods to prevent diarrhoeal diseases. The largest increases in knowledge were for handwashing with soap before food preparation events. The success of the CHoBI7 mHealth program in increasing WASH knowledge was likely attributed to the theory-driven and evidence-based approach for intervention development which included semi-structured interviews, group discussions and a pilot study [46]. To target descriptive norms, a peer role model was developed that was a mother of a child that came to the hospital with diarrhoea. This mother teaches households when to wash hands with

soap, and how to treat household drinking water, thereby increasing knowledge of these behaviours. The intervention enabling technology which included a handwashing station, chlorine tablets, sealed water vessel and cue cards likely also led to an environment that facilitated habit formation of the promoted WASH behaviours and increased knowledge on diarrhoea transmission and prevention. Through this theory-driven approach for intervention development we were able to target the contextual, psychosocial, and technological factors driving our key WASH behaviours. In addition, we attribute the significant increases in diarrhoeal disease knowledge observed to the timing of intervention delivery during a period of severe illness in these households when our WASH behavioural recommendations likely resonated the most with household members. Previous research in Asia and Africa has observed higher perceived severity of diarrhoeal diseases and benefits of water treatment during the time of diarrhoeal disease outbreaks [47,48].

Despite household members of diarrhoea patients being at a very high risk of diarrhoeal diseases, we found their baseline knowledge of diarrhoeal disease transmission and prevention to be low. This is consistent with our previous findings among household members of cholera patients, and previous community and hospital-based studies in Dhaka, Bangladesh, which found low diarrhoeal disease knowledge [34,49,50]. Furthermore, previous studies in Tanzania and the Democratic Republic of the Congo found poor diarrhoeal disease knowledge even in the context of ongoing cholera outbreaks [51,52]. These findings emphasise the need for WASH behaviour change communication programs during diarrhoeal disease outbreaks, and for programs targeting populations at high risk of diarrhoeal diseases.

In our study, few participants considered flies to be an important transmission route for spreading diarrhoeal diseases (<5%). This is despite the growing literature demonstrating that flies are a risk factor for enteric infections such as *Shigella* [53–55]. In addition, few participants reported before feeding a child, before serving food and after cleaning child faeces as key times for handwashing with soap (<10%). This is likely because our program did not focus on food hygiene and safe child faeces disposal, which are both important public health issues globally that have been traditionally understudied [56,57]. We are currently developing and evaluating mHealth modules targeting food hygiene and safe child faeces disposal (Biswas *et al.* 2020. submitted) for diarrhoea patient households.

Our study identified several misconceptions around diarrhoea transmission and prevention, and the key times to wash hands with soap. At baseline, for important ways

diarrhoea was spread some participants reported by air and spicy food. For the key times for handwashing with soap to prevent diarrhoea, at baseline some participants reported after eating and working. These results show a lack of understanding of the transmission and prevention of diarrhoea among this highly susceptible population. We also observed that some study participants reported that an important time for handwashing with soap was after touching something dirty. Previous studies have described the concept of dirt reactivity, where a 'gross feeling' on hands was a key motivator of handwashing with soap practices [58,59], rather than for example before food-related events. Future studies should target these misconceptions around diarrhoeal disease transmission and prevention.

Our study had several strengths. First, the prospective design with multiple time points for data collection allowed us to observe changes in diarrhoeal disease knowledge over a 12-month period. Second, we used open-ended questions to assess diarrhoeal disease knowledge rather than multiple-choice responses. Third, having two intervention arms one with home visits and one without home visits which allowed us to investigate the added benefits of home visits to the CHoBI7 mHealth program. Fourth, the randomised study design.

This study had a few limitations. First, the study could not be blinded because of the presence of the intervention hardware. Therefore, the interviewers knew the study arm of the households they visited. However, to minimise potential bias, the evaluation and intervention teams were separate. Third, we focused on diarrhoea patient households, and therefore, our findings may not be generalisable to other populations. Fourth, our study took place only in an urban setting. Future studies should evaluate the effectiveness of the CHoBI7 mHealth program in increasing diarrhoeal disease knowledge in rural areas of Bangladesh. Lastly, we focused on a single composite measure of diarrhoeal disease knowledge. Future studies should perform an exploratory factor analysis to determine which knowledge domains should be focused on for the development of a knowledge score of diarrhoeal diseases.

Conclusion

The CHoBI7 mHealth program significantly increased knowledge of diarrhoeal disease transmission and prevention among diarrhoea patients and their household members 12 months after in-person visits for program delivery were conducted. These findings suggest that mHealth presents a promising approach to increase diarrhoeal disease knowledge among a high-risk population in Bangladesh. Future studies are needed to investigate the efficacy of the CHoBI7 mHealth program in other settings globally.

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References

1. Troeger CFM, Rao PC, Khalil I *et al.* Estimates of global, regional, and national morbidity, mortality, and aetiologies of diarrhoeal diseases: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet Infect Dis* 2017; **17**: 909–948.
2. Estimates of global, regional, and national morbidity, mortality, and aetiologies of diarrhoeal diseases: a systematic analysis for the Global Burden of Disease Study 2015. *Lancet Infect Dis* 2017; **17**: 909–948.
3. Moy RJ, Marshall TF, Choto RG, McNeish AS, Booth IW. Diarrhoea and growth faltering in rural Zimbabwe. *Eur J Clin Nutr* 1994; **48**: 810–821.
4. Richard SA, Black RE, Gilman RH *et al.* Diarrhea in early childhood: short-term association with weight and long-term association with length. *Am J Epidemiol* 2013; **178**: 1129–1138.
5. Black RE, Brown KH, Becker S. Effects of diarrhea associated with specific enteropathogens on the growth of children in rural Bangladesh. *Pediatrics* 1984; **73**: 799–805.
6. Bairagi R, Chowdhury MK, Kim YJ, Curlin GT, Gray RH. The association between malnutrition and diarrhoea in rural Bangladesh. *Int J Epidemiol* 1987; **16**: 477–481.
7. Lutter CK, Mora JO, Habicht JP *et al.* Nutritional supplementation: effects on child stunting because of diarrhea. *Am J Clin Nutr* 1989; **50**: 1–8.
8. Baumgartner RN, Pollitt E. The Bacon Chow Study: analyses of the effects of infectious illness on growth of infants. *Nutr Res* 1983; **3**: 9–21.
9. Walker SP, Grantham-McGregor SM, Powell CA, Himes JH, Simeon DT. Morbidity and the growth of stunted and nonstunted children, and the effect of supplementation. *Am J Clin Nutr* 1992; **56**: 504–510.
10. Checkley W, Epstein LD, Gilman RH, Black RE, Cabrera L, Sterling CR. Effects of *Cryptosporidium parvum* infection in Peruvian children: growth faltering and subsequent catch-up growth. *Am J Epidemiol* 1998; **148**: 497–506.
11. Moore SR, Lima AA, Conaway MR, Schorling JB, Soares AM, Guerrant RL. Early childhood diarrhoea and helminthiasis associate with long-term linear growth faltering. *Int J Epidemiol* 2001; **30**: 1457–1464.
12. Checkley W, Epstein LD, Gilman RH, Cabrera L, Black RE. Effects of acute diarrhea on linear growth in Peruvian children. *Am J Epidemiol* 2003; **157**: 166–175.
13. Mondal D, Petri WA Jr, Sack RB, Kirkpatrick BD, Haque R. Entamoeba histolytica-associated diarrheal illness is negatively associated with the growth of preschool children: evidence from a prospective study. *Trans R Soc Trop Med Hyg* 2006; **100**: 1032–1038.
14. Sudfeld CR, McCoy DC, Danaei G *et al.* Linear growth and child development in low- and middle-income countries: a meta-analysis. *Pediatrics* 2015; **135**: e1266–75.
15. Liu L, Oza S, Hogan D *et al.* Global, regional, and national causes of child mortality in 2000–13, with projections to inform post-2015 priorities: an updated systematic analysis. *Lancet (London, England)* 2015; **385**: 430–440.
16. Elegbe I, Juba A. Partnership with nursing mothers: an interim strategy for combating childhood enteric diseases in Nigeria. *Child Care Health Dev* 1988; **14**: 51–58.
17. Dikassa L, Mock N, Magnani R *et al.* Maternal behavioural risk factors for severe childhood diarrhoeal disease in Kinshasa, Zaire. *Int J Epidemiol* 1993; **22**: 327–333.
18. Bertrand WE, Walms BF. Maternal knowledge, attitudes and practice as predictors of diarrheal disease in young children. *Int J Epidemiol* 1983; **12**: 205–210.
19. Wolf J, Hunter PR, Freeman MC *et al.* Impact of drinking water, sanitation and handwashing with soap on childhood diarrhoeal disease: updated meta-analysis and meta-regression. *Trop Med Int Health* 2018; **23**: 508–525.
20. Michie S, Prestwich A. Are interventions theory-based? Development of a theory coding scheme. *Health Psychology* 2010; **29**(1): 1.
21. Inauen J, Mosler H-J. Developing and testing theory-based and evidence-based interventions to promote switching to arsenic-safe wells in Bangladesh. *Journal of health psychology* 2013; **1359105313493811**.
22. Contzen N, Meili IH, Mosler HJ. Changing handwashing behaviour in southern Ethiopia: a longitudinal study on infrastructural and commitment interventions. *Soc Sci Med* 2015; **124**: 103–114.
23. Taylor N, Conner M, Lawton R. The impact of theory on the effectiveness of worksite physical activity interventions: a meta-analysis and meta-regression. *Health Psychology Review* 2012; **6**(1): 33–73.
24. Webb TL, Joseph J, Yardley L, Michie S. Using the internet to promote health behavior change: a systematic review and meta-analysis of the impact of theoretical basis, use of behavior change techniques, and mode of delivery on

- efficacy. *J of Med Internet Res* 2010; **12**: e4. <https://doi.org/10.2196/jmir.1376>.
25. Dreibelbis R, Kroeger A, Hossain K, Venkatesh M, Ram PK. Behavior change without behavior change communication: nudging handwashing among primary school students in Bangladesh. *Int J Environ Res Public Health* 2016; **13**: 129.
 26. George CM, Biswas S, Jung D *et al.* Psychosocial factors mediating the effect of the CHoBI7 intervention on handwashing with soap. *Health Educ Behav*. 2017; **44**: 613–625.
 27. George CM, Perin J, Neiswender de Calani KJ *et al.* Risk factors for diarrhea in children under five years of age residing in peri-urban communities in Cochabamba, Bolivia. *Am J Trop Med Hyg* 2014; **91**: 1190–1196.
 28. Deb BC, Sircar BK, Sengupta PG *et al.* Studies on interventions to prevent eltor cholera transmission in urban slums. *Bull World Health Organ* 1986; **64**: 127–131.
 29. Glass RI, Svennerholm AM, Khan MR, Huda S, Huq MI, Holmgren J. Seroepidemiological studies of El Tor cholera in Bangladesh: association of serum antibody levels with protection. *J Infect Dis* 1985; **151**: 236–242.
 30. Hughes JM, Boyce JM, Levine RJ *et al.* Epidemiology of eltor cholera in rural Bangladesh: importance of surface water in transmission. *Bull World Health Organ* 1982; **60**: 395–404.
 31. Mosley WH, Ahmad S, Benenson AS, Ahmed A. The relationship of vibriocidal antibody titre to susceptibility to cholera in family contacts of cholera patients. *Bull World Health Organ* 1968; **38**: 777–785.
 32. Spira WM, Khan MU, Saeed YA, Sattar MA. Microbiological surveillance of intra-neighbourhood E1 Tor cholera transmission in rural Bangladesh. *Bull World Health Organ* 1980; **58**: 731–740.
 33. Weil AA, Khan AI, Chowdhury F *et al.* Clinical outcomes in household contacts of patients with cholera in Bangladesh. *Clin Infect Dis* 2009; **49**: 1473–1479.
 34. Saif-Ur-Rahman KM, Parvin T, Bhuyian SI *et al.* Promotion of cholera awareness among households of cholera patients: a randomized controlled trial of the cholera-hospital-based-intervention-for-7 days (CHoBI7) intervention. *Am J Trop Med Hyg* 2016; **95**: 1292–1298.
 35. Figueroa ME, Kincaid DL. Social, cultural and behavioral correlates of household water treatment and storage. Household water treatment and safe storage Geneva: World Health Organization. 2007.
 36. George CM, Monira S, Sack DA *et al.* Randomized controlled trial of hospital-based hygiene and water treatment intervention (CHoBI7) to reduce cholera. *Emerg Infect Dis* 2016; **22**: 233–241.
 37. George CM, Jung DS, Saif-Ur-Rahman KM *et al.* Sustained uptake of a hospital-based handwashing with soap and water treatment intervention (Cholera-Hospital-Based Intervention for 7 Days [CHoBI7]): a randomized controlled trial. *Am J Trop Med Hyg* 2016; **94**: 428–436.
 38. Zurovac D, Sudoi RK, Akhwale WS *et al.* The effect of mobile phone text-message reminders on Kenyan health workers' adherence to malaria treatment guidelines: a cluster randomised trial. *Lancet (London, England)* 2011; **378**: 795–803.
 39. Cole-Lewis H, Kershaw T. Text messaging as a tool for behavior change in disease prevention and management. *Epidemiol Rev* 2010; **32**: 56–69.
 40. Free C, Phillips G, Galli L *et al.* The effectiveness of mobile-health technology-based health behaviour change or disease management interventions for health care consumers: a systematic review. *PLoS Medicine* 2013; **10**: e1001362.
 41. Higgs ES, Goldberg AB, Labrique AB *et al.* Understanding the role of mHealth and other media interventions for behavior change to enhance child survival and development in low- and middle-income countries: an evidence review. *J Health Commun* 2014; **19**(Suppl 1): 164–189.
 42. Gibson DG, Ochieng B, Kagucia EW *et al.* Mobile phone-delivered reminders and incentives to improve childhood immunisation coverage and timeliness in Kenya (M-SIMU): a cluster randomised controlled trial. *Lancet Global Health* 2017; **5**: e428–e438.
 43. George CM, Monira S, Zohura F *et al.* Effects of a Water, Sanitation and Hygiene Mobile Health Program on Diarrhea and Child Growth in Bangladesh: A Cluster-Randomized Controlled Trial of the CHoBI7 Mobile Health Program. *Clinical Infectious Diseases* 2020: In Press.
 44. Mosler H-J. A systematic approach to behavior change interventions for the water and sanitation sector in developing countries: a conceptual model, a review, and a guideline. *Int J Environ Health Res* 2012; **22**: 431–449.
 45. Dreibelbis R, Winch PJ, Leontsini E *et al.* The integrated behavioural model for water, sanitation, and hygiene: a systematic review of behavioural models and a framework for designing and evaluating behaviour change interventions in infrastructure-restricted settings. *BMC Public Health* 2013; **13**: 1015.
 46. George CM, Zohura F, Teman A *et al.* Formative research for the design of a scalable water, sanitation, and hygiene mobile health program: CHoBI7 mobile health program. *BMC Public Health* 2019; **19**: 1028.
 47. Dunston C, McAfee D, Kaiser R *et al.* Collaboration, cholera, and cyclones: a project to improve point-of-use water quality in Madagascar. *Am J Public Health*. 2001; **91**: 1574–1576.
 48. Figueroa MEKD. Social, cultural and behavioral correlates of household water treatment and storage. Household Water Treatment and Safe Storage. World Health Organization. 2007.
 49. Wahed T, Kaukab SS, Saha NC *et al.* Knowledge of, attitudes toward, and preventive practices relating to cholera and oral cholera vaccine among urban high-risk groups: findings of a cross-sectional study in Dhaka, Bangladesh. *BMC Public Health* 2013; **13**: 242.
 50. Tamason CC, Tulsiani SM, Siddique AK, Hoque BA, Mackie Jensen PK. What is cholera? A preliminary study on caretakers' knowledge in Bangladesh. *J Health Popul Nutr* 2016; **35**: 3.

51. Merten S, Schaetti C, Manianga C *et al.* Local perceptions of cholera and anticipated vaccine acceptance in Katanga province, Democratic Republic of Congo. *BMC Public Health* 2013; **13**: 60.
52. Schaetti C, Khatib AM, Ali SM, Hutubessy R, Chaignat CL, Weiss MG. Social and cultural features of cholera and shigellosis in peri-urban and rural communities of Zanzibar. *BMC Infect Dis* 2010; **10**: 339.
53. George CM, Ahmed S, Talukder KA *et al.* Shigella infections in household contacts of pediatric shigellosis patients in rural Bangladesh. *Emerg Infect Dis* 2015; **21**: 2006–2013.
54. Cohen D, Green M, Block C *et al.* Reduction of transmission of shigellosis by control of houseflies (*Musca domestica*). *Lancet* 1991; **337**: 993–997. [http://dx.doi.org/10.1016/0140-6736\(91\)92657-N](http://dx.doi.org/10.1016/0140-6736(91)92657-N)
55. Levine OS, Levine MM. Houseflies (*Musca domestica*) as mechanical vectors of shigellosis. *Rev Infect Dis* 1991; **13**: 688–696. <http://dx.doi.org/10.1093/clinids/13.4.688>
56. Morita T, Godfrey S, George CM. Systematic review of evidence on the effectiveness of safe child feces disposal interventions. *Trop Med Int Health* 2016; **21**: 1403–1409.
57. Nizame FA, Unicomb L, Sanghvi T *et al.* Handwashing before food preparation and child feeding: a missed opportunity for hygiene promotion. *Am J Trop Med Hyg* 2013; **89**: 1179–1185.
58. Scott B, Curtis V, Rabie T, Garbrah-Aidoo N. Health in our hands, but not in our heads: understanding hygiene motivation in Ghana. *Health Policy Plan* 2007; **22**: 225–233.
59. Hirai M, Graham JP, Mattson KD, Kelsey A, Mukherji S, Cronin AA. Exploring determinants of handwashing with soap in Indonesia: a quantitative analysis. *Int J Environ Res Public Health* 2016; **13**: 868.

Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1 Reported Diarrhoea Knowledge Score by Category.

Corresponding Author Christine Marie George, Associate Professor, Department of International Health, Program in Global Disease Epidemiology and Control, Johns Hopkins Bloomberg School of Public Health, 615 N. Wolfe Street, Room E5535, Baltimore, MD 21205-2103, USA. Tel.: +1 410955 2485; E-mail: cmgeorge@jhu.edu